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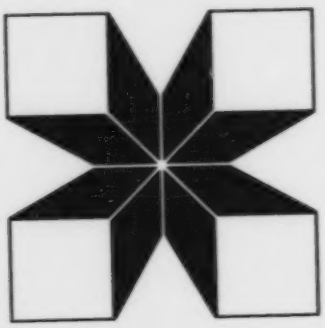

CANADA

MARICULTURE RESEARCH AND DEVELOPMENT IN JAPAN

AN EVOLUTIONARY REVIEW

F. BRIAN DAVY

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Mariculture research and development in Japan

An evolutionary review

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Executive Summary

Mariculture is a subset of aquaculture, involving the husbandry of aquatic organisms in marine waters. Japan is likely the most advanced nation in the world in terms of mariculture production. The evolution of Japanese mariculture and its relation to technology development is the objective of this review, particularly in terms of future policy direction. Japanese mariculture production has a long history, but it only increased markedly since World War II, based primarily on the increased production of high-priced species. High market demand, with increasing prices (without high prices, it was probably not possible); decreases in the Japanese distant water fisheries; and strong leadership by the Japanese government at various levels are some of the reasons for the success of these programs.

The research and technology transfer system of the major species (i.e., yellowtail, red sea bream, oyster, Kuruma prawn, and the seaweed nori) leading to these production increases is reviewed. During the postwar period, production of all major species increased through mariculture, complementing the wild-caught fishery. Based on the Japanese experience, it is suggested that other less-developed countries (LDCs) could utilize some related strategies for improving the production of similar desirable species and as a means of raising the income of coastal fishermen. Many LDCs are already trying the traditional system of marine cage culture, but based on the Japanese experience, these countries should also consider developing sea farming or marine ranching. This system of releasing fish seed into coastal areas for later capture by the existing fishery has resulted in significant increases in catches. Although there are still questions about the overall economics of this practice, such a program merits careful examination by other countries, particularly those having a developed mass seed production technology.

A variety of trends and issues are highlighted as key factors in the present and future development of mariculture in Japan. Development of a regionally based research system with research programs aimed specifically at solving production problems for the priority species was and continues to be a crucial factor in the rapid development of Japanese mariculture. This is particularly important when coupled with an effective technology dissemination system. Also, the issue that is often forgotten and that has contributed greatly to the success of Japanese mariculture is the fact that most fishery rights and control of much of the culture area were given to the local fisheries cooperative association to which most fishermen belong. This system forces all other inputs, including new technology from the research system, to follow along these lines.

There are problems ahead, however, such as the self-pollution of culture areas and the need for more holistic approaches to overcome the lower quality of

life of coastal fishermen relative to other sectors. The self-pollution problem demonstrates what happens when farms are allowed to increase production without any consideration for the carrying capacity of the environment. LDCs must develop their own guidelines and make sure that development does not take place in an unchecked manner.

The need for continued technology development and refinement in the disciplines of reproduction, nutrition, genetics, and disease is also reviewed; despite Japan's advanced state of aquaculture development, there are still technology gaps in these disciplines. For instance, the self-pollution problem is partly a nutrition problem brought on because the Japanese mariculture industry still depends primarily on "trash fish" as the main feed input. However, the trend seems to be toward developing complete artificial diets with less-polluting characteristics. Mass seed production is well developed, but natural spawning as opposed to induced spawning is the preferred method. In genetics, little classical selection and hybridization has been done on the main mariculture species. For the future, biotechnological approaches are being tried. Disease research, particularly related to the self-pollution problem, has received much attention, but increasing drug usage and drug dependence by the industry for the treatment of diseases is raising a variety of concerns.

At present, there are almost 100 species of fish under various stages of production. The method of choosing new culture species and the system of seed production for these new species, for both the traditional cage culture systems and the newer sea farming systems, is described.

Japan is now moving in the direction of placing even greater emphasis on high technology through a series of large-scale projects, such as Marine Forum 21, which involves national and prefectural government laboratories as well as the private sector.

1. Introduction

During the initial stages of my study, I read an interesting article in the Los Angeles Times (1989) that struck a responsive chord in my mind regarding my sabbatical and the future directions of countries in our world. This article was describing the trend toward larger groupings of countries after the signing of the Canada - United States Free Trade Agreement, but of interest to me was its singling out research as follows. It prophesied that "the 21st century will belong to conglomerates of nations who have found a way to motivate their people to work, save, produce and create. It will be the century of those who have developed new scientific paradigms in their research and thinking as frames through which to view the new world in the forming."

In a similar way, my hope was to develop "a different way of looking at how we do what we do." As will be seen in this review, I am interested in identifying new paradigms. At present, I am torn between a logical scientific examination versus an historical and evolutionary one.

Due to my scientific training, I have always been looking for a more systematic and logical approach to my work; one way to describe my interests would be "research on developing country research systems." One possible framework for this approach may be drawn from Hilborn's (1987) writings on uncertainty in resource management. Most resource managers face large degrees of uncertainty in their work, e.g., a lack of detailed information on the environment in which one works (in this case, the research system in developing countries), uncertainty or limited control over the system followed to accomplish research goals (research conducted by LDC staff under the local bureaucracy), a lack of information and control over the process of reaching the end-user through research (small-scale fishermen/farmers) and uncertainty over available resources (both future donor agency support and recipient country inputs - sometimes too much support is provided all at once, but more often too little support is available), difficulties in evaluating feedback for the purpose of improving planning (evaluation methodologies are poor and research evaluation has a nebulous quality to it, particularly in developing countries).

Hilborn (1987) advocates a two-stage approach: (1) identifying and classifying uncertainties and (2) developing strategies for their solution. As a theoretical framework, I found this useful because I have been putting more emphasis on identifying and classifying uncertainties while continuing to develop strategies for their solution. Although I am not a taxonomist by training, there is a need for a better definition of the environment in which we work and classification based on levels of uncertainty seems as useful as any other approach.

Hilborn (1987) cites three types of uncertainty for which I have tried to give examples in parentheses related to research in developing countries: (1) anticipated states of uncertainty that one learns to live with (e.g., delays in research start-up, changes in project staff, and other inherent delays that one often calls "bureaucracy"), (2) uncertain states of nature (longer term (3-5 year) planning based on uncertain future resources, both from donor agencies and LDCs, for problems that both the donor and the recipient have identified as being priorities), and (3) unanticipated events (revolutions, major shifts in national plans and policies, or other national problems that interrupt the research and dissemination system).

The strategy advocated by Hilborn (1987) is adaptive management, particularly for infrequent uncertainties. This strategy is based on the reality one sees in resource management, where one can often only try a suggested management action and then subsequently evaluate the result (ex post evaluation). Therefore, one must know with certainty where one is and have a good monitoring system to check the results of the initial stages of a project and then modify actions quickly based on this feedback. A flexible system with a fast response time is needed. Particularly when dealing with surprise (infrequent uncertainty), resource management strategy includes holding some resources in reserve to cope with the unexpected and developing a broadly based monitoring system to facilitate early detection of problems. Much of this reasoning may seem like common sense and equally applies to life in general. Nevertheless, it provides a possible framework to follow and possible guidelines for strategic planning and allocation of resources. As indicated in later sections, I am particularly interested in improving strategic planning in aquaculture and the need to look at this issue in a variety of new ways. More attention needs to be given to asking the right questions to be attacked through research.

One opportunity seems to be greater exploration of the interfaces between different disciplines (the new scientific paradigms discussed earlier) and an examination of their points of interaction. The need to examine problems from a broader, more holistic view seems to be a global trend brought about by the increasingly complex problems facing society and a recognition that quick fixes are not real solutions. I recognize that much of the review that follows has a bias toward biotechnical issues due to my past training and present interests. Nevertheless, I have tried to look at more than just biology and its related technology. As will be seen later, I believe that the need for a more holistic approach and inadequate linkages even among the biological disciplines were responsible for some of the problems in the development of Japanese mariculture.

Another opportunity in my view is an historical review of comparable systems in "developed countries," including an examination of their evolution in situ followed by looking for possible parallels in the "developing or less developed

country" situation. Generally, most people are not at all excited about historical treatises, myself included. However, often there is value in looking back and trying to learn from past mistakes. This is the intention in this approach. I was greatly influenced by the writings of Mayr (1982) in which he forcefully argues that most scientific problems are far better understood by studying their history than their logic. Science is practiced by people and is inseparable from the intellectual, institutional, and social milieu of the period. Emphasis should be placed on working scientists and their conceptual world. What were the problems of their time? What were the conceptual and technical tools available to scientists in their quest for a solution? What methods could they employ? What prevalent ideas of the period directed their research and influenced their decisions? Also, as will be seen in the review that follows, I believe that the evolution of research systems in relation to development objectives, particularly better definition of the initial starting point of the research, has not been given the attention that it requires in fisheries and aquaculture. I have tried to raise both of these issues in this review.

1.1 Objectives

My general objective was to review recent advances in mariculture in Japan and to use this information as a basis for planning and managing programs in developing countries, particularly in Asia. The approach used was primarily based on a review of available literature (mostly written in English, although I was able to get limited amounts of material translated) plus site visits combined with interviews with key Japanese personnel involved in mariculture research and development.

Mariculture is the culture or husbandry of aquatic organisms in marine waters, and for the purposes of this review is considered to be part of aquaculture. Included in this definition is the fact that someone owns the aquatic organism and that this ownership issue is of vital importance. I have chosen mariculture to provide a needed focus for this review and because increasing amounts of research support in recent years have been allocated to this topic. At present, although aquaculture in the fisheries sector is showing increases in production on a global basis, most of these increases are from freshwater rather than seawater. However, as indicated by a number of authors (e.g., Bardach et al. 1972; Shang 1986), mariculture is the sector of aquaculture that is most likely to make strides in the coming decades. For a number of years, there has been a major concern in my mind regarding means of increasing the efficiency of funding support in cooperation with national and regional fisheries institutions. This concern was one of the reasons behind my application for this study leave.

At present, there are limited studies on the technology-transfer process in aquaculture. Attacking this issue was also one of my goals as this issue is

fundamental to the success of projects as they enter the information dissemination phase.

For this review of mariculture in Japan, I have chosen to focus on the impact of new mariculture technology on the various production processes. A broad definition of technology has been adopted. Technology here includes production hardware as well as all the skills, knowledge, and procedures for making, using, and doing useful things. I have tried to document various examples of new technology impacts on a selected species basis. I have chosen the "problematic history approach" described by Mayr (1982) in combination with a chronological history. My hope is that this review may provide some guidance in terms of related mariculture development in other countries, particularly in Southeast Asia where similar increases in production from coastal zones are taking place (e.g., Thailand or the Philippines) or are projected (e.g., Indonesia or Sri Lanka). I have also documented two new research technologies that have just been developed and are now beginning the dissemination process, one via the private sector and the other via the public sector. Hopefully, these case histories will provide more specific details on the dissemination and user-feedback process and how it works in Japan.

1.2 Why Japan?

There are several reasons for using the development of mariculture in Japan for this analysis. The main reason is that Japan has one of the longest histories of mariculture in the world, bearing in mind that mariculture is a relatively new field of food production compared with other sectors of agriculture or fisheries. Also, Japan is a very "technology intensive" country. Particularly since World War II, major emphasis has been placed on the development of new technology; major increases in fish production are one of the results of the introduction of this technology (Fujiya 1989). Of course, there have been a variety of trade-offs associated with this development, but from the point of view of examining the research and development process, Japan provides a useful case history. Finally, Japan probably has the widest variety of advanced mariculture technologies of any country in the world, mixed with an increasing number of fish species being cultured. This mix of culture system and species is also reviewed here.

To some people, Japan is the first Asian country to become a developed country; to others, it is a very costly "hi-tech" society, very unlike resource-poor farms in developing countries elsewhere in Asia. In part, these statements are true, but Japan is also a small farm agricultural country. As will be seen in a later chapter on the Japanese fish farmer, the same small-scale factor also applies to its coastal fisheries and mariculture. Intensification in production has

developed rapidly, particularly since the Meiji Restoration and then again after World War II. It is important to keep in mind this small farmer orientation when reading this review.

Some authors have argued against using the Japanese experience in other countries (particularly developing countries) (e.g., Williamson 1971). Although the differences between the Japanese situation and that in other developing countries, especially other Asian countries, should be examined critically, there seems to be a series of similar factors (e.g., related species, culture systems, consumer-demand functions, and traditions) providing parallels in development; hence, the justification for this review. In addition, Japanese technology and systems are increasingly being tried by other Asian countries anyway. As indicated in this review, this trend will likely increase in the future.

Aquaculture, like agriculture, is now known to have a site-specific nature for much of its technology. Examination of Japanese mariculture, taking into consideration this site specificity (i.e., by evaluating it in terms of the local context that led to the specific developments), seems to be crucial to this approach. I have tried to do this plus include information leading to these developments. Likewise, this technology cannot be transferred as is to other Asian countries without local testing and adaptation.

Recently, there has been an increasing awareness that aquaculture on a worldwide scale is reaching a critical period (e.g., Liao 1989). Aquaculture must be developed based on judicious evaluation of its strengths and constraints. An historical review of what worked (and what has not), with some indication of why, may help in this effort.

1.3 Research System

I assume that there will be no misunderstanding of what is research. A useful definition that I found in Andrew and Hildebrand (1982) states that "research is the orderly procedure by which man increases his knowledge and is contrasted to accidental discovery because it follows a series of steps designed precisely for the purpose of developing information." However, it is recognized that there are different categories of research, particularly with respect to short-term and long-term timetables. The following definitions, pertaining to agriculture and used by the Consultative Group on International Agricultural Research (CGIAR), seem to be useful and are followed here.

(1) Basic research: that designed to generate new understanding (e.g., how the partitioning of assimilates is influenced by plant height).

(2) Strategic research: that designed for the solution of specific research

problems (e.g., developing a technique for detecting dwarfing genes in wheat seedlings).

(3) Applied research: that designed to create new technology (e.g., breeding new varieties of dwarf wheat that can respond to high levels of nitrogen without lodging).

(4) Adaptive research: that designed to adjust technology to the specific needs of a particular set of environmental conditions (e.g., incorporating dwarf wheats into farming systems of the rainfed areas of the Pampean region of Argentina).

It should be noted that although these definitions are listed as discrete entities they are in fact part of a continuum.

To provide a better picture of the present system of research contributing to the development of this technology, I have tried to document the Japanese research system as it relates to mariculture. Much of this information is not readily accessible in English; therefore, this review may be useful to other workers interested in Japanese mariculture development. One related but unstated objective of my study was to make more of the Japanese mariculture information available. The reference list at the end of this review will help in this regard.

1.4 Strategic Planning in Mariculture

The long-term objective of my work is to contribute to the fisheries planning process of fisheries departments, other national government planning bodies related to fisheries, and other organizations (e.g., donor organizations). An initial literature review uncovered almost no published papers on strategic planning in mariculture or aquaculture. Retrospective searches were run on AGRIS, CAB, and ASFA data bases using the keywords fish and program and/or planning. My hope is to see the development of strengthened short-term and long-term goals in developing country institutions. Improved criteria to enable more rational decision-making are needed to set appropriate goals, to ensure proper allocation of resources, and to facilitate project evaluation. I will return to this point in the section on future trends.

2. Historical Development of Mariculture in Japan

In this section, I have tried to review the development of mariculture and to indicate the main issues related to this development. Some parallels seem to exist with other Asian developing country situations and specific references are made to these throughout the text.

Fish has been an important commodity in Japan since earliest times. Japan is composed of four main islands: Hokkaido, Honshu, Shikoku, and Kyushu (Fig. 1). The total area of Japan is about 369,000 km^2 and a large part of this area is occupied by mountains, which have hindered the development of animal husbandry to a large extent. By contrast, Japan possesses a very productive coastal zone that is almost equal in size to the land area (the continental shelf is 310,000 km^2) and fish is readily available. It should also be noted that in early times the traditional religion, Buddhism, discouraged the eating of meat. Also, fishery products are now embedded in Japanese culture. On festive occasions or as special gifts of thanks or congratulations, fish, such as red sea bream, Kuruma prawn, or seaweed, are often given. Therefore, a variety of pressures led to the preference for fish, especially marine fish, as the main

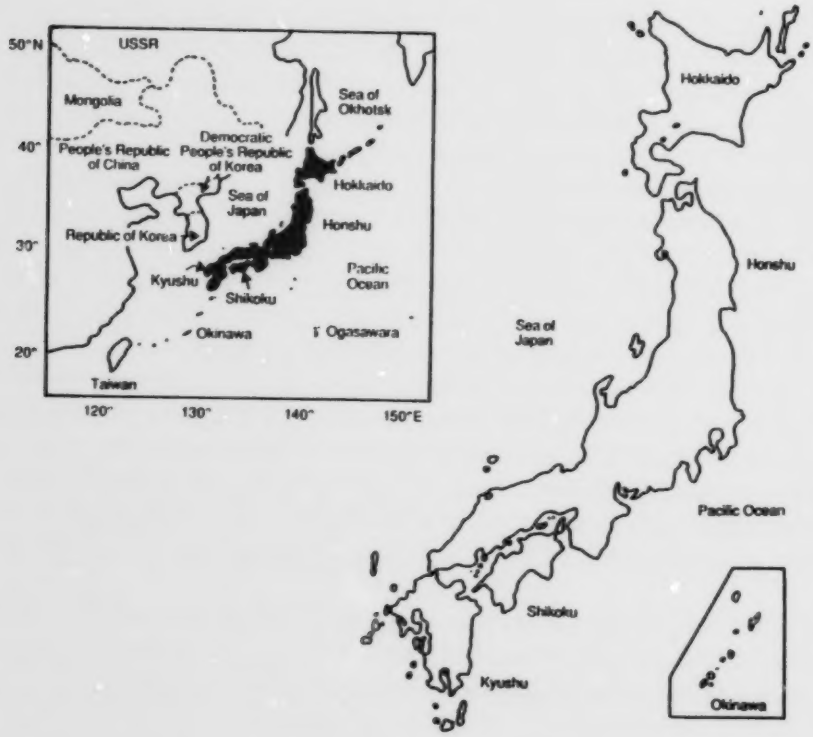

Figure 1. Map of Japan.

source of protein in the diet. In recent years, this overriding preference for fish has diminished somewhat, but Japan still has one of the highest levels of consumption of fish products in the world, 65.0 kg of whole fish (or 35.8 kg of edible fish) per capita per annum compared with 25.4 kg of whole fish for other developed countries and 7.7 kg for developing countries. In terms of animal protein per capita, expressed on a daily basis, the level in Japan is 18.7 g (1986 data).

Mariculture has a relatively long history in Japan compared with most other countries, with oysters (Crassostrea gigas) and seaweed (Porphyra sp., Undaria sp., and Laminaria sp.) being the main species that have been raised for centuries. Transplanting clams and macroalgae (such as the seaweed species listed above) began in the 8th and 11th centuries respectively (Tamura 1956 in Nagata and Hirata 1986). Transplanting oysters began as early as the 17th century with the development of a new spat collection technology using bamboo poles and culture on poles in 1677 (Nagata and Hirata 1986). Red tides were first identified in Wakayama Prefecture in the year 731. Unfortunately, there are few accounts written in English on the early history of mariculture.

Ogura (1967) provides some useful guidelines on agricultural development in Japan and a brief summary of the salient features is given here. Japan was the first Asian nation to modernize and did so only over the last 100 years. Prior to this, Japan was essentially an agricultural nation, similar to most Asian developing countries that became independent after World War II. Levels of productivity in agriculture were similar to those existing in other Asian developing countries at present. Farming was based on a traditional small scale subsistence farming system dominated by a feudal hierarchy. In 1868, at the beginning of the Meiji Restoration, productivity was 1.8 t/ha; by 1956, this had been increased to 4.0 t/ha. The main point of interest to other developing countries was that this rapid increase in farm productivity took place without destroying the small scale farming system. The average size of a farm was 1.0 ha (the average arable land area per worker was less than 0.5 ha) in 1878 and 0.8 ha in 1962. During this period, Japan was able to increase productivity without significantly reducing the labour force and without adopting capital-intensive methods of production, at least on any large scale. Agricultural development was able to provide food for the growing population, supply needed foreign exchange, and provide investment resources for other sectors plus raw materials for industry within the overall development process. The following issues were crucial:

(1) New technology (irrigation and land improvement, superior seeds, better methods of crop cultivation, and increased inputs of manures and fertilizers): this allowed for high yields within this small scale farming system.

(2) Provision of incentives to farmers to increase production: this was accomplished mainly by creating a new system of land tenure and land taxation and a supporting monetary system.

(3) Dissemination of technology to the farming population: this was achieved through the development of a network of research institutions, and extension and educational systems.

(4) Development of a cooperative system to provide credit as well as purchasing and marketing services and as a channel for other incentives: this involved price supports and production subsidies.

(5) Significant attention was paid to organization, including the necessary institutional systems; policies were then applied with exceptional thoroughness.

Of interest is the fact that technology from the "West" was imported, but in the final analysis much of this technology was inappropriate to the small scale farming system and led to failures. Most of the useful technical advances were based on indigenous knowledge, with very selective use of imported technology. Much of this indigenous technology resulted from studying and propagating the methods of the best Japanese farmers and selecting indigenous varieties of the main crops. In fact, the early extension program in 1885 used instructors from the Komaba Agricultural School (later to become the University of Tokyo, College of Agriculture) plus veteran farmers (rono) to travel around the country. This combined the best practical farming experience with the new knowledge of the inexperienced college graduates (Hayami and Ruttan 1985). In terms of tailoring technology to local factor endowments, the major priority was to develop technology that would increase land productivity. For instance, early technology development centred on the increased use of fertilizer (as a substitute for limited land). Technology related to development and dissemination of new seed varieties that produced higher yields with increasing fertilizer inputs coupled with expansion of the fertilizer industry (increased production, lower cost, improved distribution) were key developments.

It appears likely that many of the same principles affected the development of mariculture, although probably at a later date than agriculture. For instance, similar to agriculture, aquaculture has been targeted almost totally at the small fish farmer and large scale industrial farms cannot operate in most sectors as they are unable to obtain the necessary permit to culture in the sea. This issue is discussed further in a section on the Japanese farmer.

Significant mariculture development only took place in this century. Total production from mariculture in the coastal zone grew slowly from 23,000 metric tonnes in 1912 to 76,000 metric tonnes before the start of World War II (Table 1). Note that Japanese mariculture statistics do not include salmon. Only

Table 1. Fishery production - summary of catch by fishery sector, 1915-1987.

Year	Total		Marine fisheries		Marine cultures		Inland water fisheries		Inland water cultures	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1915	2032	-	2000	-	28	-	4			
1920	2482	-	2434	-	42	-	5			
1925	2845	-	2795	-	39	-	8			
1930	3186	-	3135	-	37	-	13			
1935	3977	-	3864	-	93	-	19			
1940	3526	-	3428	-	78	-	19			
1945	1824	-	1750	-	61	-	12			
1946	2107	-	2075	-	24	-	6			
1947	2286	-	2257	-	25	-	4			
1948	2518	-	2477	-	36	-	4			
1949	2761	-	2666	-	55	-	40			
1950	3373	-	3255	-	48	-	63	-	5	-
1951	3930	-	3774	-	88	-	60	-	6	-
1952	4823	-	4646	-	113	-	53	-	9	-
1953	4598	-	4387	-	144	-	57	-	8	-
1954	4541	-	4304	-	145	-	82	-	9	-
1955	4907	-	4658	-	154	-	82	-	11	-
1956	4772	2310	4488	2012	180	206	90	62	13	30
1957	5407	2582	5067	2303	244	174	81	73	14	31
1958	5506	2569	5198	2267	214	205	78	70	15	37
1959	5884	2877	5568	2535	225	236	75	69	15	36
1960	6192	3448	5817	2983	284	338	74	80	15	47
1961	6710	3952	5287	3340	322	455	81	93	18	64
1962	6864	4266	6397	3567	362	538	84	94	20	68
1963	6698	4830	6200	3988	389	650	84	98	23	94
1964	6350	4976	5868	4039	362	724	89	102	29	111
1965	6908	5558	6382	4516	380	816	113	101	33	126
1966	7103	6260	6558	5005	405	974	103	118	36	164
1967	7851	7026	7241	5677	470	1074	97	109	42	166
1968	8670	7448	7993	6097	522	1010	103	119	52	221

(continued)

Table 1. Concluded.

Year	Total		Marine fisheries		Marine cultures		Inland water fisheries		Inland water cultures	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1969	8613	8488	7976	6928	473	1130	112	144	52	285
1970	9315	9692	8598	7852	549	1353	119	170	48	317
1971	9909	10894	9149	8957	609	1374	101	214	50	349
1972	10213	11796	9400	9417	648	1708	109	231	56	441
1973	10763	14641	9793	11564	791	2252	114	299	64	528
1974	10808	17084	9749	13789	880	2325	112	348	67	622
1975	10545	18870	9573	15204	773	2536	127	417	72	713
1976	10656	21862	9605	17702	850	2933	124	415	77	811
1977	10757	25451	9688	20513	861	3522	126	386	82	930
1978	10828	24511	9683	18914	917	4013	138	508	90	1076
1979	10590	26480	9477	20559	883	4229	136	527	95	1164
1980	11122	27712	9909	21336	992	4687	128	578	94	1110
1981	11319	27779	10143	21525	960	4454	124	625	92	1064
1982	11388	29640	10231	23129	938	4556	122	709	96	1248
1983	11968	29032	10697	22053	1060	5186	117	624	94	1170
1984	12816	24236	11501	22316	1111	5171	107	607	97	1233
1985	12171	28902	10877	21919	1088	5222	110	608	96	1154
1986	12739	27182	11341	20357	1198	5080	106	614	94	1130
1987	12464	25877	11129	19253	1137	4922	101	623	97	1080

Note: Quantities are expressed in thousand metric tonnes; values are expressed in hundred million yen.

after World War II did production begin to increase dramatically. Much of this recent development was based on the culture of species with high market prices (e.g., red sea bream, Pagrus major; yellowtail, Seriola quinqueradiata; Kuruma prawn, Penaeus japonicus; and left-eye flounder, Paralichthys olivaceus). These species were almost all fed high protein diets, usually supplied by feeding them low value fish, e.g., sardine (Sardinops melanosticta), jack mackerel (Trachurus japonicus), and sand lance (Ammodytes personatus), which are landed in large quantities by the fishing industry. It is useful to note the importance of the feeding issue in much of this evolution of mariculture.

This postwar increase in production was due to a variety of factors: (1) increasing consumer demand for quality fish products fueled by the overall improvement in the economy of Japan; (2) the preference of Japanese consumers for live fish or very fresh fish (consumers were willing to pay high prices for good quality) coupled with the capability of the mariculture industry to meet this demand; (3) imposition of the 200 mile (320 km) Extended Economic Zone by most nations and the consequent decrease in the Japanese distant-water fisheries; and (4) specific Japanese government programs designed to enhance mariculture development (e.g., marine ranching, Marine Forum 21, etc.) as a mechanism to compensate for the decrease in distant-water catches.

At present, Japan is usually recognized as the leading nation in the world for mariculture development. Despite this long history of mariculture, the science of mariculture in Japan (research and technology development) has a very recent history, only really developing in the postwar era. Development of the science of mariculture appears to correspond to the major postwar increase in production as noted above. However, this relatively recent scientific approach to mariculture means that there are still research gaps and institutional development problems, particularly in developing countries, but even in advanced countries such as Japan. I will return to this issue in the chapter on the research system.

Mariculture in Japan now has become separated into two general types:

(1) Traditional land- and water-based culture systems: Suspended floating structures, such as rafts and longlines, are used for oysters and seaweeds; floating cages, fixed tanks, pens, and ponds are used for finfish and crustaceans.

(2) Sea ranching (sometimes called sea farming): Seedlings are produced in shore-based hatcheries and are then released into open waters where they grow and are subsequently harvested by the existing fisheries. Sea ranching is well developed in Japan and its status and development have been reviewed by a number of authors (Nose 1981; MAFF 1988; Watanabe 1988a; Matsuoka 1989). The traditional culture systems are reasonably well developed in LDCs, but sea ranching is relatively unknown and merits more detailed examination (see Chapter 6 for details).

A brief review of the early development of traditional finfish culture systems up to the time when statistical data were compiled separately for each species is given in Table 2 to further illustrate the evolution of mariculture. Subsequent developments are described in more detail in the next chapter under each species.

These statistics include only finfish; yellowtail, pufferfish, and, later, red sea bream were the main species. As indicated in Table 2, there was a gradual increase in the number of farms (in Ministry of Agriculture, Forestry and Fisheries statistics, these are referred to as management units, which I have assumed to be farms); there were also periods of decreasing numbers. This took place over a 10 year period until enough confidence was developed by the industry to embark on this new technology in a large way, resulting in the rapid increase in production that followed. I was only able to find fragments of data on an individual species basis. There were no mariculture statistics listed in the Ministry of Agriculture, Forestry and Fisheries annual report in 1952. In 1953, there were five yellowtail farms, all in Ehime Prefecture. In 1954, there was only one yellowtail farm in operation, utilizing 10 workers; this farm was located in neighbouring Kagawa Prefecture. As expected, not all farms were initially successful.

In recent years, major problems have occurred related to intensification of traditional culture systems beyond the carrying capacity of the coastal zone, i.e., too many fish are grown in a given area and aquaculture wastes (e.g., feces and uneaten food) accumulate on the sea bottom, resulting in eutrophication and associated water quality problems, which then lead to major disease problems. For instance, 30-50 cm of sludge has been found on the bottom below some cage culture sites. These activities have also been correlated with the occurrence of red tides. Shirota (1989) has reviewed this point in the Seto Inland Sea and indicates that the frequency of red tides from 1970 to the peak in 1976 follows

Table 2. Finfish mariculture evolution.

Date	Number of Farms	Area (1000 m^2)	Yield (t)
1953	5	-	78
1954	35	-	53
1955	36	-	68
1956	38	-	64
1957	47	1267	112
1958	19	324	293
1959	38	1186	542
1960	71	1927	1431
1961	298	2116	2704
1962	357	4108	5200

the increasing Japanese economy and the increasing production of yellowtail. When the first oil shock hit Japan in 1973, there was a slowdown in the Japanese economy, followed by a decrease in red tide frequency with a time lag of 2-3 years. This pattern of development has been repeated for each species over and over again; as technological problems, such as mass seed production, feeding, or culture system engineering were overcome, the industry expanded too rapidly. There would appear to be some lessons here for others to avoid. This problem of aquaculture wastes, called self-pollution by some Japanese, has resulted in major reexamination of mariculture development policies. For instance, sea farming is now receiving increasing emphasis and systems for culture in deeper offshore (and less polluted) waters are now being developed under Marine Forum 21. I will come back to these issues in later sections as these are fundamental to the trends that have developed in Japan.

Sea ranching has evolved from its introduction in 1963 in the Seto Inland Sea to become a major public sector funded program designed to partially offset the losses suffered in the coastal fisheries by pollution and industrial development. Earlier fisheries cooperative associations had started some propagation projects, but these were primarily centred on sedentary species, such as shellfish. Initially, two prefectural centres were established and attempts to solve technological problems associated with mass seed production were started. There was a period of about 10 years of trial and error development and by the 1970s mass seed production technology of Kuruma prawn was first worked out, followed by red sea bream. Based on these results, a national network of centres was started in 1973. These became part of an organization called Nihon Saibai Gyogyo Kyokai (The Japan Sea Farming Association (JSFA)), which now has 14 seed production centres distributed throughout Japan. Further developments in JSFA are given in a later chapter on present production trends. In addition, all prefectural governments, as well as some city and town governments, established similar mass seed production centres, which now total more than 50 centres. At present, there are more than 64 mass seed production centres involved in sea farming.

3. Fish Production: Major Species

This chapter presents a detailed description of technology development for selected major species. Species selection is based on a number of factors: (1) present monetary value to Japanese mariculture; species valued at more than 10 billion yen are considered to be major species; (2) representation of a range of species groups; in this case, two finfish, one crustacean, one mollusc, and one seaweed species; (3) representation of a correspondingly broad range of feeding levels as feeding is a major issue (feeding at the primary, secondary, and tertiary trophic levels); and (4) selection of major Japanese species for which there are corresponding species of present major production importance or with future potential in developing countries of Asia to provide a basis for comparison.

3.1 Yellowtail

At present, yellowtail, Seriola quinqueradiata, is the major mariculture finfish species in Japan, contributing about 70% of marine finfish production. As shown in Figure 2, when production started to increase, it increased rapidly until 1985, when it began to decrease as demand appeared to have been surpassed. Present production has leveled off at about 150,000 t. Many producers switched to other species, such as red sea bream and more recently flounder and striped jack (Pseudocaranx dentex), when the yellowtail market became saturated.

As shown in Figure 2, yellowtail culture was first started in 1928 at Adoike, Kagawa Prefecture, by Sakichi Noami (Matsusato 1978). Initially, the culture system for yellowtail was based on stocking wild-caught mojako (yellowtail fry) in pond-like enclosures along the seacoast that had small gates to allow the entrance of tidal water; subsequently, pens were used, which involved putting a net across a small bay or enclosure to allow greater water exchange. The level of production did not increase much, however, until 1954-1955, when the floating cage culture system for growing most marine species was developed by researchers at Kinki University. Today, this culture method almost totally dominates as it is much more efficient in terms of increased water circulation, which is clearly the major factor when higher levels of stocking are used to obtain increased production. This increase in production was also aided by decreasing catches of wild yellowtail (presently less than 36,000 t) and the rapid increase in demand for many high quality marine species that followed the general increase in the standard of living in Japan during the postwar period.

Useful summaries of yellowtail culture can be found in Kafuku and Ikenoue (1983), Watanabe (1988a,b), and Korringa (1976b). The Aquaculture Data Book (Planning Board of all Japan Coastal Fishery Development 1976) provides a useful pictorial summary of Japanese yellowtail technology.

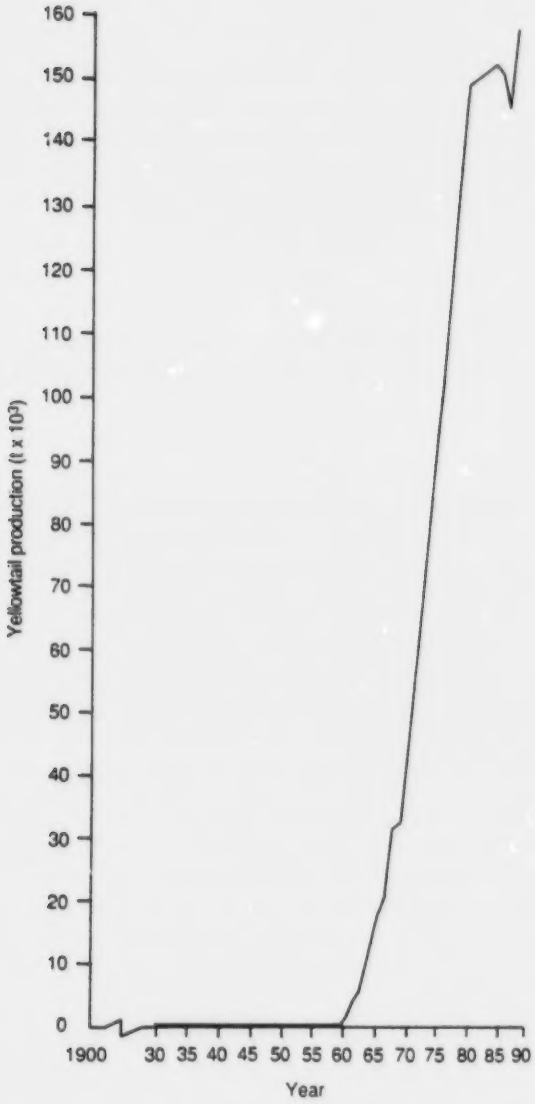

Figure 2. Evolution of yellowtail culture.

3.1.1 Reproduction

Yellowtail culture in cages is still dependent on the collection of fry from the wild despite the fact that mass seed production has recently been perfected by some JSFA centres. This problem of mass seed production also sets a limit on further increases in production as the catch of wild fry is strictly regulated by the

government under a licencing system. All JSFA seed (1.93 million seedlings in 1988) is used for their release programs. Therefore, it seems likely that artificial seed for the cage culture industry will be developed in the future if quality seed at a competitive price can be produced. Related to the issue of interdisciplinary research, it is now likely that a broodstock diet will be needed in the near future.

3.1.2 Nutrition

Culture is carried out in sheltered bays in central and southern Japan (Fig. 3). The grow-out phase is based on feeding low value fish (Fig. 4a) (frozen or fresh, then minced or chopped and often then mixed with a dry formulated powder to form a moist pellet) at a rate of 4-8% of body weight and at a frequency of three to four times per day for fish weighing less than 100 g. These levels and the frequency of feeding are dependent on water temperature and fish weight. Feeding is mainly carried out by hand using a shovel or by pumping the feed from a grinder on the farmer's boat (Fig. 4b). If culture conditions are good (i.e., water temperature of 18-27°C, specific gravity >1.015, and dissolved oxygen >5 mL/L in the net cage), the fish grow very rapidly (Fig. 5), attaining a weight of 1 kg within 1 year (Watanabe 1988a,b). In fact, yellowtail is one of the marine species with the fastest rate of growth of all finfish cultured in Japan.

It appears that yellowtail production may have reached a plateau of about 150,000 t in recent years. Much of this plateau effect appears to result from disease problems related to poor feed-water quality. This self-pollution problem is partially explained in Figure 6, which shows the release of feed and wastes into the water. This partitioning, using nitrogen as an example, illustrates that only 72% of the feed is consumed by the fish, with 15 and 3% of this amount being released into the water as urine and feces respectively. Therefore, one can see the high levels of eutrophication that result in areas of intensive culture. Methods of dealing with this problem are discussed later. However, if a higher quality cultured product (the present cultured fish has a very soft texture and a greasy taste due to excessive amounts of fat in the flesh) can be produced, there are likely opportunities to increase production still further (T. Watanabe, personal communication). This problem may be partially solved by the development of a new dry pellet for yellowtail as this diet is formulated to better meet consumer demands for fish flesh that is closer to the wild-caught product in terms of colour, lustre, smell, texture, taste, and degree of greasiness. It is still too early to predict the likely uptake of this new technology.

In the early years of yellowtail culture, farmers used 8 m x 8 m x 8 m cages, but they are now rearing yellowtail in larger cages (20 m x 20 m x 8 m or larger) with lower stocking densities for longer durations to produce a better tasting product with a larger market weight (3.5-4 kg). This technique of lowering productivity to improve the quality of the product and increase or maintain

Figure 3. Yellowtail cage culture in coastal bays. (a) Yusu Cooperative, Uwajma Ehime Prefecture: overall culture area; (b) close-up of (a); (c) Gokasho Bay, Mie Prefecture.

Figure 4. (a) Feeding a moist pellet by shovel. (b) Trash fish (sardine) in plastic boxes before feeding into the grinder. (c) Grinder and water pumping feed down the pipe to the cage. This device is also used for feeding soft dry pellets.

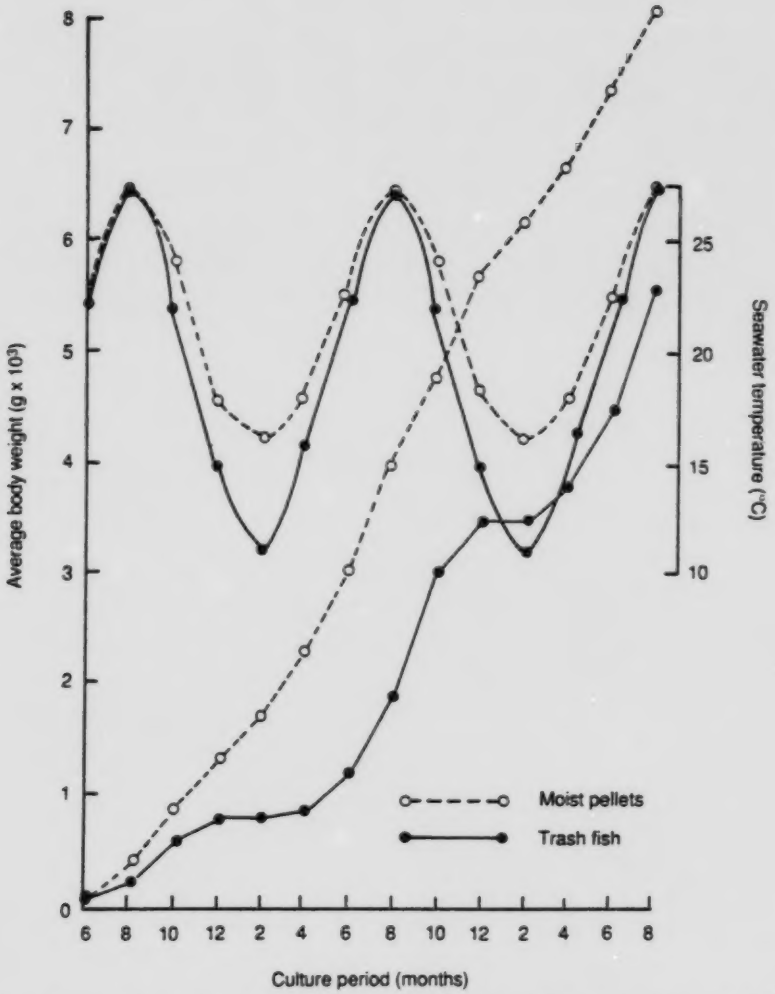
Average body weight (g x 10³)
Seawater temperature (°C)
Moist pellets
Trash fish
Culture period (months)
6 8 10 12 2 4 6 8 10 12 2 4 6 8

Figure 5. Growth curves of juvenile yellowtail (mojako) to full adult size (buri) during 2 years after feeding with moist pellets and trash fish (after Watanabe 1988a).

profitability is discussed later. This approach illustrates that fish culturists, through experimentation, are doing more and more to meet the demands of the market.

3.1.3 Genetics

Little work has been undertaken on this topic, presumably due to the limited development of mass seed production techniques. Harada (1975) tried the following hybridization experiments:

Seriola quinqueradiata (female) x Seriola lalandi (male)
Seriola dumerili (female) x Seriola lalandi (male)

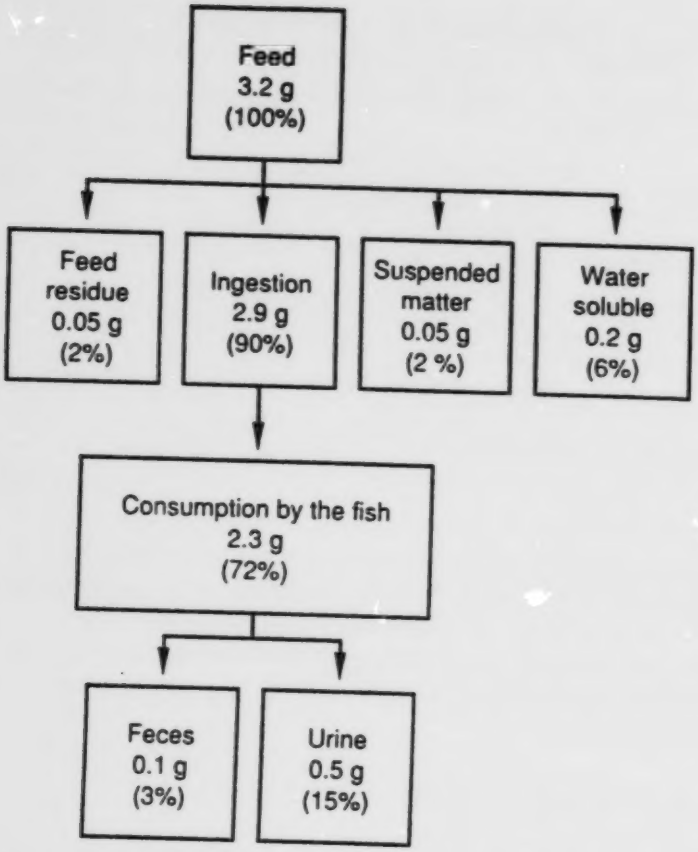

Figure 6. Feed partitioning (N) related to the self-pollution problem (after Matsusato 1978).

The results were never applied on a large scale by the industry, however, due to the limited increase in growth rate of the hybrids.

3.1.4 Disease

Disease problems in yellowtail became quite serious shortly after the rapid increase in production in the 1960s. In 1972, for instance, yellowtail losses due to disease were valued at 600 million yen (Table 3). Parasitic diseases caused by monogenetic trematodes, Vibriosis, Pasteurellosis, Nocardiosis, some nutritional diseases, then red tides followed by Streptococcosis made up a sequence of disease problems that had to be solved by scientists and the industry (see Matsusato (1978) for a list of these problems).

Table 3. Economic value of yellowtail losses from disease in 1972.

Disease	Loss (x1000 yen)
Pasteurellosis	518000
Nocardiosis	4400
Vibriosis	6000
Microsporidiosis	8200
Dropsy	0
Lymphocystis	100
Nutritional disease	50800
Mass mortality from red tide	2800
Others	4500
Total	594800

Source: Matsusato (1978).

Diseases associated with poor feeding practices also occurred. As indicated earlier, these problems are likely due, for the most part, to the self-pollution issue. Farmers now have to pay for medicine and other treatments, which has lowered their profit margins and led to rethinking of the best culture system. Maximum productivity does not always lead to maximum profitability as discussed in Chapters 6 and 7.

3.1.5 Other developments

A new submersible cage system was developed in the mid-1970s (Fig. 7) to allow expansion of the culture grounds to more open waters farther offshore as this type of cage is designed to better resist heavy wind and wave action. This cage has received limited acceptance by most farmers, however, due to associated difficulties in feeding and monitoring the fish. Some farmers around Kochi Shikoku Island, which is a very exposed area, are using it.

Fish are generally sold in the fish markets live or in a fresh-iced condition. A well-developed transport and marketing system is in place to assist in this distribution. Specific details of this system, however, are beyond the objectives of this review.

3.2 Red Sea Bream

Red sea bream (Pagrus major) is a very important marine finfish in Japan. It is now second to yellowtail in total production (currently about 40,000 t). Culture system development followed almost exactly the same pattern as that for yellowtail, but about 10 years later. The introduction of the floating net cage in the late 1950s was the major technological stimulus for the rapid expansion in

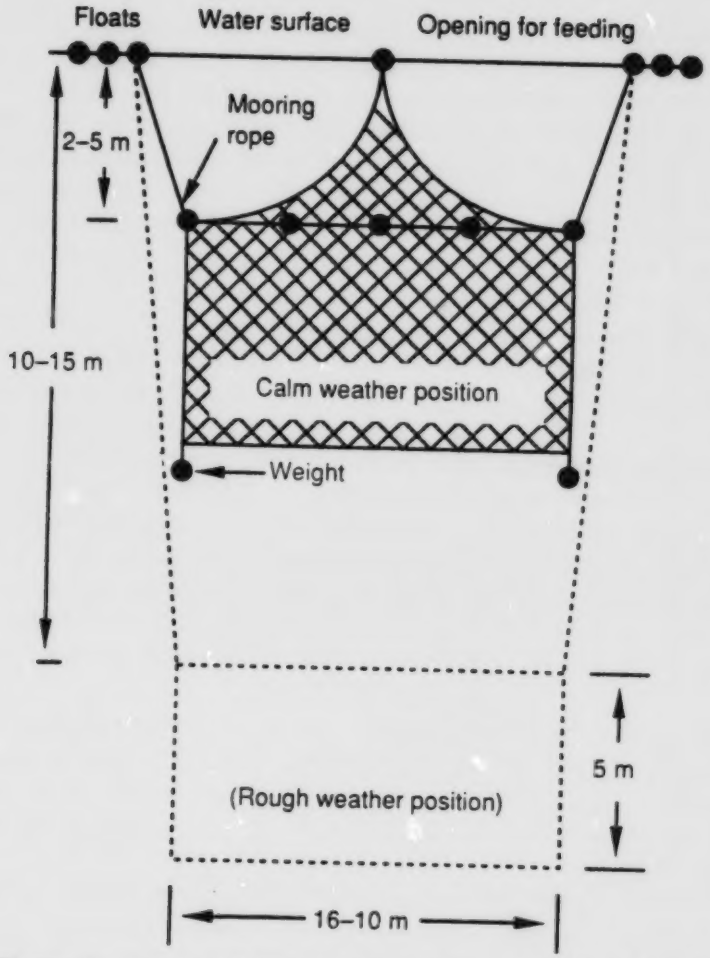

Figure 7. Submersible cage for yellowtail (after Fujiya 1976).

production that followed in the 1970s (Fig. 8). Red sea bream culture initially started in 1962 with one farm producing about 2 t. There was a 7-8 year lag before this culture really became widespread, increasing rapidly around 1970.

Foscarini (1988) provides a recent review of red sea bream intensive farming procedures. He indicates that the success and popularity of this fish are due to good knowledge of its biology and behaviour in the wild, and nutritional requirements at different stages of its culture, plus its fast growth, tolerance to a relatively wide temperature range, and ease with which it can be spawned. Kafuku and Ikenoue (1983) and Korringa (1976b) provide additional information on this species.

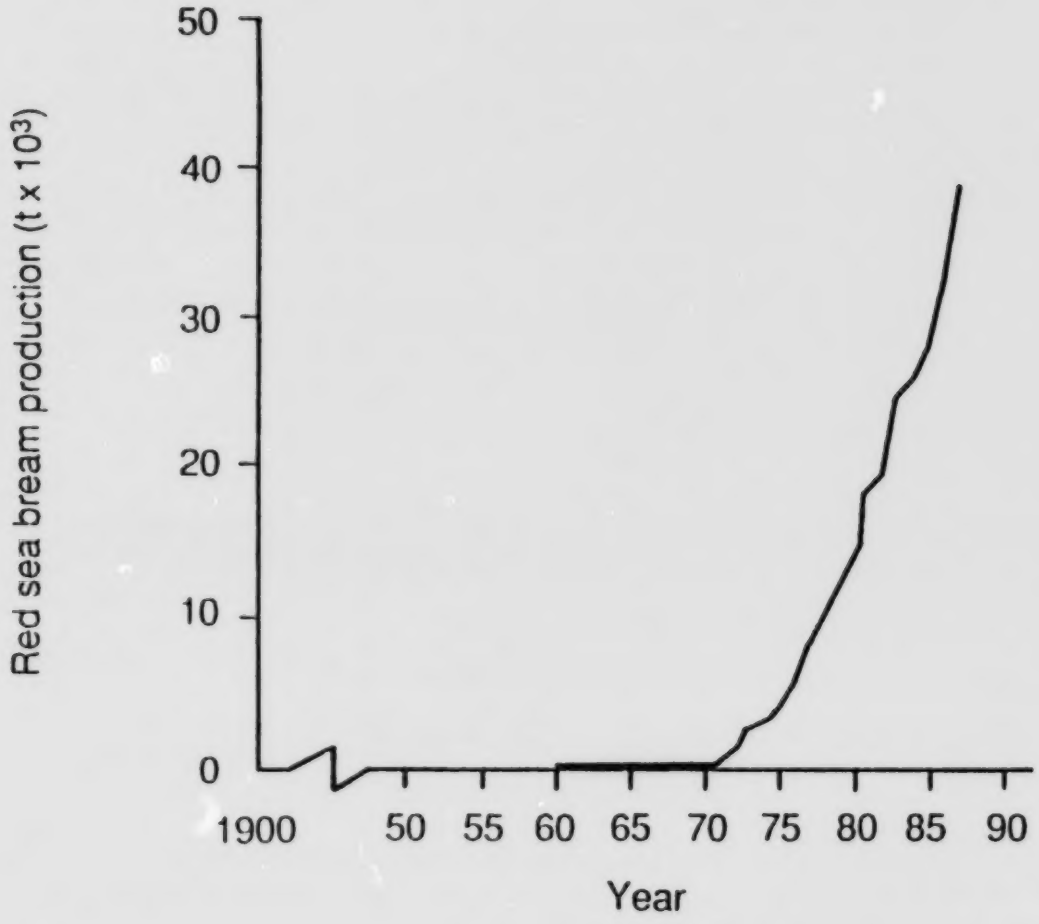

Figure 8. Evolution of red sea bream production in Japan.

3.2.1 Reproduction

Fukusho (1989) provides a recent review of red sea bream fry production. Artificial breeding and fry production were first started in Hiroshima in 1887. In 1902, the first hatchery was started, also in Hiroshima, but a variety of problems were encountered. The main problem involved the development of larval rearing technology. It was not until the late 1950s when the technology for larval rearing

related to mass seed production was finally perfected. Interestingly, much of this technology was dependent on plankton survey work, which identified a series of organisms (rotifers, wild copepods and bivalve, and sea urchin and Artemia nauplii were the main organisms) that were effective as live foods for the early stages of feeding the larvae. Initially, therefore, the key to the larval feeding problem did not come from a directed research attempt to solve the problem, but from unrelated research on plankton distribution. In 1959, researchers saw the importance of these findings and tried Artemia for feeding herring fry; other researchers then went on to perfect the technology for some of the priority aquaculture species, including red sea bream. In 1962, 22 juveniles were first produced from 150,000 eggs at a fisheries centre in Kanagawa Prefecture. Finally, in 1965, at Hakatajima, Ehime Prefecture, mass seed production was established using rotifers (Brachionus plicatilis) as live food.

Fukusho and Kitajima (1988) indicate that three main factors were responsible for the successful development of the mass seed production of marine finfish, mainly sea bream and related species: the introduction of the rotifer as a food organism, the establishment of natural spawning systems in tanks, and the improvement of environmental management for larval rearing systems.

Larval feeding systems

This topic includes research on both reproduction and nutrition. The predominance of the rotifer as a larval feed was directly related to its optimal size and high nutritional value for first feeding larvae. Maintaining adequate supplies of rotifers required the development of mass culture systems to produce this live food organism. Accordingly, this area of research has developed into an important specialized component of aquaculture, particularly due to the tremendous increase in Japanese hatchery numbers and levels of production. The rotifer is used as feed for all marine finfish species as well as most prawns/shrimps. Rotifers are usually fed Chlorella sp. (a marine algae), which are usually enriched with yeast (Fukusho et al. 1976). A wide variety of research has been carried out on the best method of enriching Chlorella (Watanabe 1987), other substitute feed organisms, and the best systems of culture and management of these feed organisms. Kanazawa et al. (1989) have recently reported on trials using artificial microbound diets for larval red sea bream. In their trials, they were able to substitute this artificial diet partially for live foods. The growth and survival rates obtained were comparable to those attained using live food alone. The development of a complete larval diet will likely be possible in the future as this feed can now be used to determine the nutrient requirements in fish larvae.

3.2.2 Nutrition

Recent information on the nutritional requirements of red sea bream can be found in Watanabe (1988a) and Foscarini (1988). The protein requirement for

the grow-out stage is 50-55% protein by dry weight, with 10 essential amino acids. Carbohydrate levels of 10-15% and fatty acid levels of 10-15% are suggested. Information on vitamin and mineral requirements is still incomplete.

Trash fish are still commonly used by farmers, but a commercial pellet is being used more and more because of its practicality and importance in maintaining water quality, despite its higher price. Fish are commonly fed krill or other high carotenoid-containing substances just before harvest to enhance the red body colour.

Broodstock are usually fed a diet high in protein beginning 1 month before the spawning season. Although a complete artificial broodstock diet has not yet been developed, Watanabe et al. (1984) and Watanabe (1985) have carried out a variety of research on practical diet development. For instance, cuttlefish meal and frozen krill were effective protein sources and n-3 (or Omega 3) highly unsaturated fatty acids (HUFA) are important as essential fatty acids. Pigments and other fat-soluble nutrients were quickly passed from the female to the eggs within a matter of hours.

3.2.3 Genetics

Genetic selection of broodstock has not as yet been practiced for red sea bream, but potential broodstock are separated, based on body conformation, from market-bound fish and kept for periods of up to 6 years for use as spawners (Foscarini 1988). However, Fukusho (in press) indicates that genetic selection for faster growth started at Kinki University in 1965 and that a strain that grows 40% faster than the wild form has reportedly been developed. Recently, "biotechnological studies" have been started using this species. In 1984, for instance, a triploid red sea bream was developed; unfortunately, the triploid had a growth rate similar to the diploid form. Additional trials were tried using gynogenesis, but the initial results were similar to those indicated above.

Recently, a red sea bream strain from Korea, with a richer red colour but slower growth rate, has been imported for possible hybridization trials with the local strain. Another variation on this plan is to hybridize the red sea bream with the crimson sea bream as the latter has an autumn maturation period as opposed to the spring maturation period of the red sea bream, which if successful would allow a longer fry supply season.

3.2.4 Disease

The overall status of red sea bream with respect to disease is presented in Foscarini (1988). Briefly, diseases have caused significant problems for red sea bream, particularly bacteria such as Vibrio sp., which have led to mortality rates

as high as 50-100%. Lordosis has caused high mortality rates in fish larvae in hatcheries. As is usually the case, improved management practices leading to better water quality and nutrition are the key factors in combatting this problem. A variety of specific drugs and vaccines have also assisted in lowering mortality rates.

3.2.5 Other developments

In 1965, methods of transporting live red sea bream were developed, mainly using tank trucks, but also airplanes and ships. Live red sea bream is a highly desired fish; hence, the importance of this technology.

Red sea bream has also been the subject of some interesting audio-signal training using acoustic conditioning techniques for feeding the young (Foscarini 1988; Hara 1988). A number of prefectural centres are now participating in this project. It has been shown that it is possible to condition young fish in holding nets. After conditioning, the nets are removed and the fish will remain in the area where the feeder and the speaker are located. Hopefully, when this research is completed, it will be possible to hold red sea bream without nets, thus reducing costs and improving feeding efficiency as feeding conditioning apparently reduces feed waste.

3.3 Kuruma Prawn

Japan is the world's largest per capita consumer of shrimps and prawns. Among these species, the Kuruma prawn is one of the most popular because of its colour and taste. Because of the high demand for these species, large quantities are imported to supplement domestic production, which comes from both fishing and culture. Present domestic production from culture is only about 2500 t (Fig. 9), but due to its high value and worldwide importance it is included here.

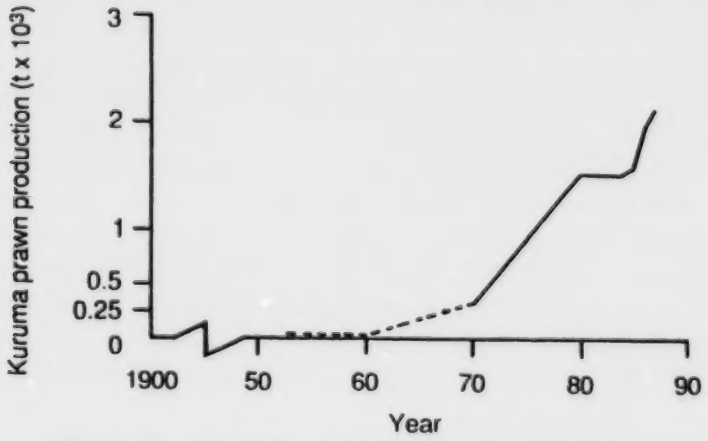

Figure 9. Evolution of Kuruma prawn culture.

The Japan Sea Farming Association and various prefectural sea farming centres release postlarvae into the sea to supplement natural stocks.

Kuruma prawn is a warm-water species, so most of the culture grounds are located in southern Japan in areas of the Seto Inland Sea, the Amakusa Islands in Kumamoto Prefecture, and Kagoshima Prefecture. Culture techniques were originally extensive in nature and began as a means of utilizing the salt pans around the Seto Inland Sea. Because of the premium price (greater than USD 50/kg) paid for live prawns and the inability of the existing fishery to fill this market niche, there has been strong economic pressure to develop a suitable culture system for this species.

In 1933, a number of biologists started work on the development of a culture technology in Kumamoto Prefecture. Shigueno (1975) provides a brief history of some of the problems encountered and developments made. Initial research focused on mass seed production, mainly the morphology and ecology of shrimp larvae. However, there was a major bottleneck in collecting the eggs of shrimp via plankton netting surveys. It was not until some of the researchers considered putting a female bearing eggs into a tank that this problem was overcome. Elucidation of the various larval stages then proceeded from this point. The next major hurdle was developing appropriate live foods for each of the shrimp larval stages. Six years later, it was found that the feeding of a diatom was the key to feeding the initial larval stages. Another key development was the introduction and development of a culture system for the rotifer Brachionus plicatilis. It was not until 1964, however, that all of this mass seed production technology reached a scale that allowed hatcheries for shrimp to be established. Therefore, most of the early research centred on seed production and larval rearing, and early shrimp farms experienced many unexpected problems, such as the direct release of hatchery-reared postlarvae into grow-out ponds where they suffered heavy mortality rates due to fish predation. Also, seaweed (e.g., Entermorpha sp.), growing unintentionally in the ponds, hid the feed that was being provided and reduced the desired habitat that the shrimp needed; as well, it acted as a pollutant when it died. Therefore, a variety of problems had to be worked out during the early days of development of the shrimp culture industry. Originally, in the Amakusa Islands of Kumamoto Prefecture, the culture system was an open, extensive system. Ponds were built along the coast and depended on the tide for water exchanges. As existing pond sites were soon used up, production increased in intensity from 400 g/m^2 to 800 or 1000 g/m^2. These productivity increases were due to the introduction of three new technologies: (1) development of a closed system using pumping rather than tidal water changes, (2) development of artificial pellet feeds, and (3) development of a mixed system of culture in which larger individuals are harvested daily and new seed are stocked.

The first shrimp farms were established in 1963 and soon many other groups followed suit. By 1974, there were 50 farms producing 600 t of prawns. In 1986, there were 154 farms producing about 2500 t of prawns. In Kagoshima Prefecture, some commercial firms (e.g., Mitsui Norrin) have developed an intensive (1 t of shrimp per 1000 m^2 tank) land-based culture system. When these tank systems were first constructed in 1972, construction costs and land prices were much less than current prices. I was told by company staff that construction of similar facilities now would not be economical; thus, no new facilities are being constructed. In addition, the Mitsui Norrin farm has since switched to mixed Kuruma ebi and flounder culture.

Kafuku and Ikenoue (1983), Korringa (1976b), and Shigueno (1975) provide useful written summaries of the complete system of prawn and shrimp culture and the Aquaculture Data Book provides a pictorial summary.

3.3.1 Reproduction

Seed production is dependent on collecting sexually mature females from the wild. Spawners are usually purchased from fishermen or related firms for approximately JPY 15,000/kg. Spawners can be identified by viewing the ovary and its state of maturity through the dorsal shell. Spawners placed in tanks at the hatchery usually spawn the following day. Prawn larvae pass through nauplius, zoea, and mysis stages and are fed live food, such as diatoms (Melosira sp., Nitzschia sp., Skeletonema sp., Thalassiosira sp., Rhizosolenia sp., and Chaetoceros sp.), rotifers (Brachionis plicatilis), and, subsequently, Artemia nauplii. As postlarvae, they are given formula food, which is later supplemented with chopped clams, mysid shrimp, and fish. After about 20 days of growth, they are harvested and supplied to culturists as seed for stocking ponds or tanks for the grow-out phase.

3.3.2 Nutrition

Kanazawa (1985, in press) and Shigueno (1985) provide recent reviews on the nutritional requirements of prawns and shrimps. Nutrition research started around 1969 on Penaeus japonicus. Now, the protein, lipid, carbohydrate, mineral, and vitamin requirements are reasonably well worked out for juvenile prawns. This species requires 52-57% protein (10 essential amino acids) for optimum growth and food efficiency. Artificial diets have now been developed that have replaced the traditional live food consisting of short-necked clams and mussels, at least in the more intensive forms of culture. Approximately 2200 t of formulated feed are used annually in Japan. Production levels greater than 10 t/ha are now being achieved under these intensive systems.

Seed production still depends on rearing the live foods listed above. This is both time consuming and expensive, so a major research thrust has focused on developing artificial feeds for the larval and postlarval stages. Microparticulate diets have been developed for these larval stages, but they are expensive and have not yet been fully developed due to inadequate knowledge of the nutritional requirements of the larvae.

3.3.3 Genetics

Very little research has been done on the genetics of P. japonicus, presumably because of the inability of researchers to breed this crustacean under controlled conditions.

3.3.4 Disease

Fungal diseases (e.g., Leucothrix sp. as a fouling organism and Fusarium as the prime cause of black gill disease) and bacterial diseases often cause high mortality rates in prawns, particularly during the larval stages. It appears that this problem is related to water quality problems associated with improper feeding or water quality maintenance problems in the pond. At the larval stage, disease problems are very much related to an inadequate understanding of larval nutritional requirements.

3.3.5 Other developments

Kuruma prawns weighing 20-25 g are harvested using an electric shocker net. They are then held in a chiller tank before they are sorted and shipped live, packed in sawdust in styrofoam boxes. Marketing is often targeted at restaurants and gift shops, with the highest prices being obtained during the New Year period.

Shrimp culture requires significant capital and operating investment, even when the semi-intensive Kumamoto pond system is used. Coastal pond operators still require a permit from the local Fisheries Cooperative Association, but there seems to be a tendency for larger and richer farmers to purchase these permits, so smaller farmers do not participate as much in shrimp culture.

There are no special government incentives to assist small operators to become involved. Anyone who can afford to do so can take up this type of culture.

3.4 Oyster

The Japanese oyster, Crassostrea gigas, has the longest history of culture of any of the mariculture species in Japan. It is a species for which there is a continuing domestic market demand despite the fact that present production has leveled off at about 250,000 t (which includes the weight of the shell; meat weights are about 10-20% of this value) and has remained there for the past 20 years (Fig. 10). This species provides a good example of a mature mariculture industry as production is steady despite increasing imports from foreign countries, especially China and Korea.

In traditional oyster culture, natural seed was collected by placing bamboo twigs in the seabed. These were left until the oysters grew to an edible size or were collected as seeds, sown on suitable hard sea bottom, and allowed to grow to an edible size (so-called bottom culture). Oyster culture production was at a level of 30,000-40,000 t until the 1950s, at which time a new hanging culture technology was introduced on a commercial scale. This hanging culture was first tested in 1923 in Kanagawa Prefecture (Koganezawa 1979), but it was not fully developed commercially until 25 years or so later. Development of this technology was probably the most significant advance in this culture system. Hanging culture involves suspending strings of oysters from racks, rafts, or longlines depending on the depth of the water. This simple innovation was crucial to increasing the productivity of the culture areas by making better use of the water column and keeping the oysters under water at all times so they could feed continuously.

Seed production was similarly affected by the introduction of the hanging technology as well as the use of cultch and its development as a specialized industry.

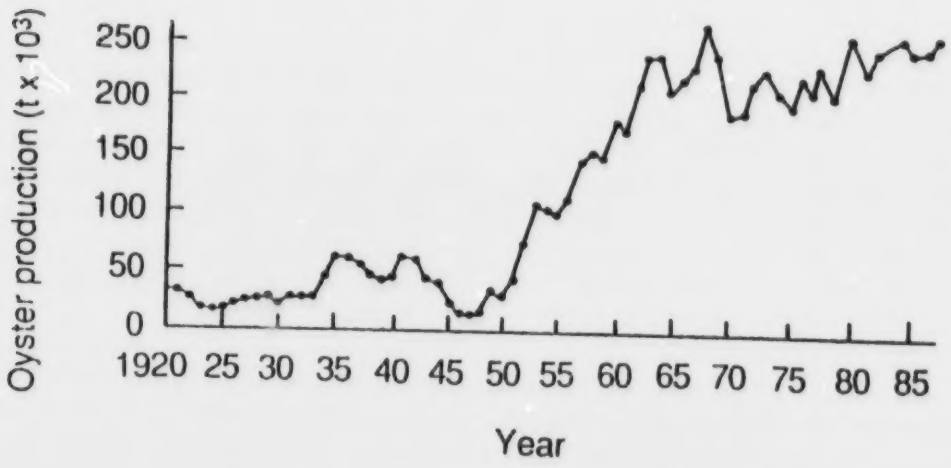

Figure 10. Evolution of oyster production.

Subsequent developments included the hardening of seed to obtain superior growth, seasonal specialization, and specialization by area within culture grounds for seed production, hardening, growing, fattening, and harvesting. At present, most major technical problems are said to have been worked out. For this reason, the government is not promoting major research on this species; another reason for this position is the relatively low market price. Oysters are typically eaten boiled or fried, but market diversification to raw shucked products or half-shell oysters is an increasing trend. Oyster culture initially suffered from price fluctuations, with prices dropping at the end of the season, but prices have now stabilized.

Oyster production is primarily concentrated around the Inland Sea near Hiroshima Prefecture and Miyagi Prefecture in northern Honshu Island. Available culture grounds are decreasing as pollution and competition from other coastal uses intensifies.

The principal oyster species is Crassostrea gigas, but there are five other local species that are either fished or cultured in small quantities plus a variety of newly introduced species, such as the European flat oyster, Ostrea edulis, and the Portuguese oyster, Crassostrea angulata, that are also being evaluated for commercial production.

Imai (1971), Bardach et al. (1972), Kafuku and Ikenoue (1983), and Koganezawa (1979) provide further details on the oyster. The Aquaculture Data Book also has a pictorial volume on abalone and oyster.

3.4.1 Reproduction

Oyster culture depends totally on natural seeds collected using special collectors called cultch. Cultch usually consists of old oyster or scallop shells that are hung on strings and suspended in the sea when adult oysters are spawning. Timing of the placement of the cultch is one of the priorities of successful mass seed production. Special surveys on the condition of spawning oysters and the occurrence of the planktonic larval stage in the sea, prior to its becoming sessile as a spat, are undertaken by each Prefectural Experimental Station in cooperation with the industry. The timing of spawning depends mainly on water temperature; a temperature above 23°C is usually required. Seed production is now a specialized industry as most culturists do not grow their own seed. It is concentrated, for the most part, in Sendai Bay, Miyagi Prefecture.

It is possible to induce spawning experimentally, but this technology has not been used in Japan as all needed seed can be produced naturally.

3.4.2 Nutrition

As oysters are filter feeders, artificial feeds are not used. Instead, feeding strategies centre mainly on identifying suitable natural fertile growing areas. Oysters feed primarily on phytoplankton and detritus, the latter being particularly important to the larger animals in terms of meeting protein and energy requirements. Oysters also take up minerals from the surrounding water. Most feeding studies have focused on defining feeding mechanisms or on growing oysters in different densities and monitoring the growth rates.

As indicated earlier, all seed production is via natural spawning. On an experimental basis, however, a hatchery technology has been developed and rearing of various types of microalgae is required as feed for the larval stages.

3.4.3 Genetics

Since defining the different strains of C. gigas, very little additional genetic research has been done on this species, likely due to the lack of further development of experimental hatchery technology.

3.4.4 Disease

A variety of oyster drills (Thais sp.) prey on oysters. Oyster culture sites are sometimes subjected to unexplained mass mortalities. These occur in 2 year old oysters in the late summer and early autumn after spawning. In 1969, the oyster industry was seriously affected by the fouling calcareous worm, Hydroides norvega. Increasing numbers of competitors, such as Hydroides, are thought to be linked to water pollution problems.

3.4.5 Other developments

As a result of their filter-feeding habit, oysters concentrate pollutants taken up from the water in which they grow. This presents a potential health hazard to the consumer, which can be overcome by purifying the oysters in "clean water." Sterilization procedures using ultraviolet radiation or ozone treatment have been developed to overcome this problem.

3.5 Nori or Purple Laver

Initially, I intended to include wakame (principally Undaria pinnatifida) and konbu (principally Laminaria japonica) culture in this review. Because the culture system is similar to that used for nori (particularly wakame), I have not repeated descriptions of these two species here. Present production of wakame and konbu is about 127,000 and 73,000 t respectively (1984 statistics).

Nori (primarily Porphyra yezoensis) is the most widely consumed seaweed in Japan as it is typically eaten with rice. It is produced as a dried rectangular sheet (20 cm x 20 cm; 3-4 g dry weight) and may be broiled lightly; it is then cut into smaller pieces and seasoned with soy sauce to eat with rice.

Present production levels for nori are about 400,000 t (wet weight), with culture areas being located primarily along the Pacific coast in central and southern Japan. At present, there appears to be an oversupply of nori, mainly "lower quality nori," which has depressed the incomes of nori farmers. This problem is compounded by a decreasing demand for nori of inferior quality, which is likely related to decreasing rice consumption.

To stabilize the economic position of the industry in the future, Saito (1979) indicates that farmers will have to produce a high quality product (i.e., less "low quality nori"), reduce production costs, and increase unit productivity. He foresees subdividing the industry into two groups: one group involved in mass production of nori and the other group involved in small-scale operations that produce a special quality of nori. It is unlikely that domestic consumption will increase, so some attempts are also being made to develop markets overseas, e.g., in the United States, as nori is not consumed very much outside Japan, Korea, and China.

Nori has been cultivated since the 1600s, but prior to World War II, production levels were relatively low, reaching levels of only 30,000-40,000 t (Fig. 11). Culture initially began in Tokyo Bay around 1675 (Okamura 1909). Similar to oyster culture, early nori culture involved sticking leafless branches of bamboo or similar trees into the seabed at the surface of the water in September to October. Within 2-4 weeks, the spores would settle on the branches and develop into the thallus stage. The branches were subsequently moved into more fertile coastal waters and allowed to grow to harvest size.

By 1902, culture had spread through a number of neighbouring prefectures around Tokyo. By this time, culture had become an organized industry, managed by cooperatives and private companies.

Despite the early development of a culture system, it was not until 1949 that it was discovered where the monospores came from and that the conchocelis stage was not a separate shell-boring algae species as originally thought. This clarified the gaps in the life cycle and allowed more rational development of a refined culture system.

Other early problems centred on too little or too much exposure to the air or improper positioning of the thallus in the water column, e.g., positioning at the surface increased the probability of freshwater occurrence, which was lethal to the growing plant.

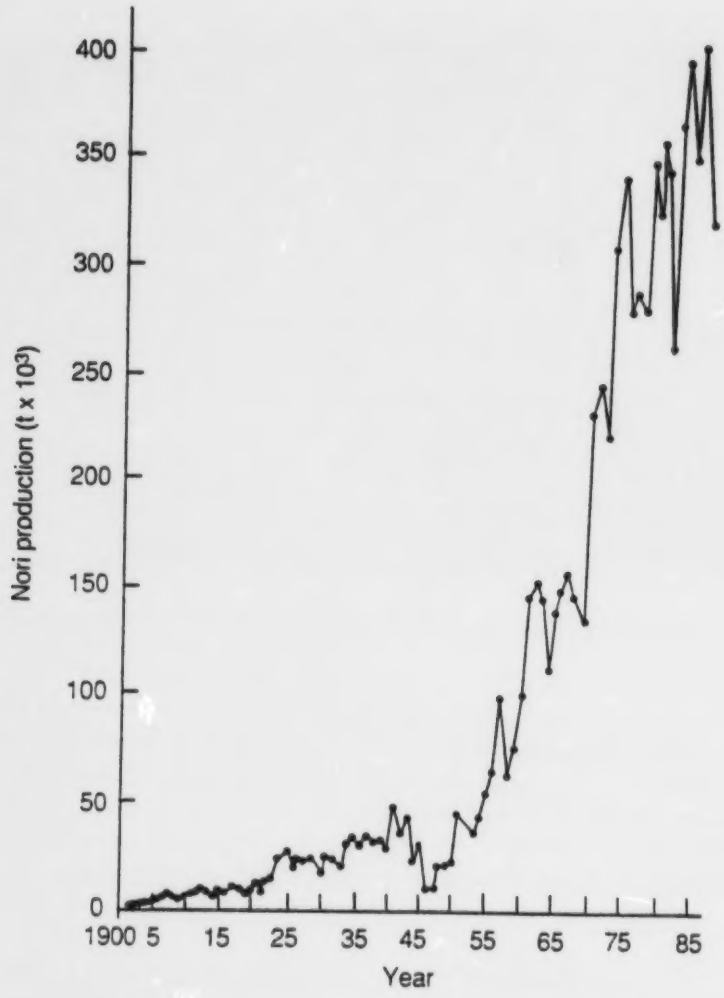

Figure 11. Nori (laver) production (after Kafuku and Ikenoue 1983).

From the mid-1950s, the introduction of new technologies, such as net cultivation on horizontal frames, cultivation with an open water system of floating nets, artificial seeding of conchospores, low temperature storage of the nursery nets, and mechanization of the nori drying process, resulted in major increases in production levels.

Nori is now grown on nets set horizontally on racks (Fig. 12) at the surface of the sea or suspended from floating nets. The culture season usually extends from October to April. Seedlings are produced from spores released from the conchocelis filament stage. Seedlings are collected in the sea or in tanks on nursery nets from the conchocelis filaments that have been allowed to grow on

Figure 12. Aunori culture on nets set horizontally on racks in Gokasho Bay, Mie Prefecture.

oyster shells. After about 15-20 days, they are visible to the eye on the nets. After 40-50 days, they are ready for cultivation in the grow-out phase or they can be stored in the freezer for later cultivation. Frozen spores are viable for more than 6 months. The thalli were harvested every 2-3 weeks throughout the winter. When productivity of a net decreases greatly, it is replaced with a new net from the freezer.

Imai (1971) and Saito (1979) provide summaries of some of the information available on nori. The Aquaculture Data Book provides a pictorial description.

3.5.1 Reproduction

Initially, seed production was primarily by natural methods and spore numbers fluctuated widely. The introduction of artificial germination techniques of the conchospores in the sea or in tanks and the possibility of freezing these seedling nets allowed staggered stocking and the possibility of 2-3 crops per year.

3.5.2 Nutrition

As nori takes its nutrients from seawater, it does not require feeding. Most early research involved finding the most fertile growing areas in the coastal zone.

Subsequent research has defined nutrient requirements plus the effects of growth promotors, such as Fe, Mn, Co, and Cu. Some trials have been initiated on artificial fertilization (usually nitrogen as it is often limiting in seawater). This nutrient supplementation is used by farmers when growth rates drop due to inadequate availability of nutrients.

3.5.3 Genetics

With the introduction of artificial seeding procedures, selection and hybridization trials have been initiated and populations of P. yezoensis and P. tenera have been developed that are more resistant to disease and grow faster.

In addition, exotic species of Porphyra have been introduced from Argentina, Canada, and the Federal Republic of Germany. It is expected that this area of research will receive even greater attention in the future.

3.5.4 Disease

In 1963 and 1965, diseases started occurring and crops started to fail. A fungal disease called red rot, Pythicum sp., combined with low temperatures, was initially thought to be responsible. Now, it is believed that the disease was related to overintensification of the culture system, leading to carrying capacity problems. High stocking densities resulted in decreases in the velocity of water currents and a reduction in available nutrients, thus making the plants more susceptible to disease.

More rational stocking densities combined with reclamation of culture grounds to improve water exchange have improved this situation.

Other diseases, such as Ascidian bacteria disease, Leucothrix, white rot, hole rot disease, diseases caused by benthic diatoms, and a variety of undefined diseases, as well as tumors, bud damage, and cold damage, have been noted.

3.5.5 Other developments

Nori is processed into dried sheets by the farmers. Nowadays, the process is mechanized as follows: The harvested nori fronds are washed in seawater, chopped into small pieces, and freshwater is added to make a suspension. The suspension is then poured into a small frame and dried in a hot air drier. After drying, the nori sheets are peeled off the frame and packaged for marketing.

Another interesting concept for improving seaweed propagation involves the aquatic afforestation programs being undertaken (mainly by government bodies) to renew previously depleted stocks by means of habitat-enhancement

techniques. This technology involves providing artificial substrates, blasting rocky reefs, weeding, controlling harvesting methods and periods, transplanting new broodstock, and artificial seeding. Seaweed beds are also important as natural nursery areas for many other fish species; thus, they serve this additional function in the habitat-enhancement programs.

4. The Research System Related to Mariculture

The aim of this section is to describe briefly the present research and education system, how it operates, and how technology is disseminated.

Japan has developed a strong institutional research capability, with regional specificity and close interaction with fish farmers. It seems obvious that one of the factors leading to the postwar increase in mariculture production was the development of this institutional capacity. Information on this issue can be found in the following sources: Asian Fisheries Society (1988), Japan Fisheries Association (1987), and Hara (1988).

4.1 Structure and Function

Research is primarily carried out by (1) the Fisheries Agency under the Ministry of Agriculture, Forestry and Fisheries (MAFF); (2) prefectural fisheries experiment stations (under the prefectural government); (3) the Japan Sea Farming Association, under MAFF; (4) universities, mostly under the Ministry of Education; and (5) private sector companies (Fig. 13).

Research policies and priorities are set as follows. At the national level, within MAFF, there is the Agriculture, Forestry and Fisheries Research Council, a consultative organ consisting of a chairman, six members, and a secretariat. Its function is to plan and coordinate research activities, administer and supervise national research institutes, assist in research activities pursued in various institutes operated by prefectures and other organizations, and liaise between research institutes and administrative organizations. In general, each research institute has funds for ordinary studies and project studies. Project studies fall under three themes and are selected by the Research Council. Further details on the Research Council are available in a publication entitled Present Situation of Research Relating to Agriculture, Forestry and Fisheries (MAFF 1986). It is important to note that only one of the secretariat counsellors focuses on fisheries and that this person is usually a middle-level fisheries researcher seconded from MAFF for a 2-3 year period.

Universities and national research laboratories concentrate on more basic research problems, whereas prefectural stations deal with more applied research problems. Because there is a prefectural laboratory in each prefecture, each deals with regional problems. Each prefectural station is under the guidance of the national laboratories. As strong linkages develop between the different laboratories, joint projects are becoming more common. This is illustrated in Figure 13, but it is also important to note the flow of funds within this system. The structure of the research system allows a good mix between basic and applied research. More importantly, however, the siting of research stations at the

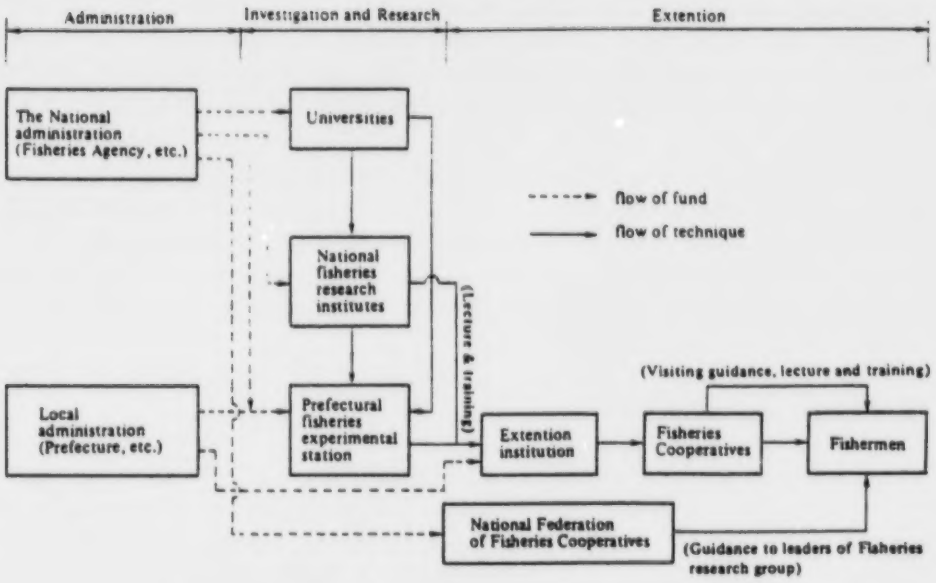

Figure 13. Fisheries research and extension system.

regional level allows for local adaption of research results from national and international studies. As indicated by Harwood (1979), this approach is critical to developing appropriate technology to meet the needs of the farmers.

Research networking does not seem to exist, at least not on a formal basis. However, the same result is obtained through linkages developed between the national laboratory and a prefectural laboratory and the increasing use of large projects to tackle problems facing the industry. There also seems to exist an informal series of networks mainly related to professors and the location of their former students in government laboratories and private sector firms. This family approach to research collaboration seems to be quite effective.

4.2 Funding

Research funding, as might be expected, follows a variety of routes, but mostly originates from MAFF (Fisheries Agency), prefectures, or the Ministry of Education.

In Japan, as in most other countries, individual scientists submit proposals for funding based on their interests, earlier training, and perception of future scientific needs and impacts. However, relevant research is increasingly being sought by research managers and planners. As in most countries, serious problems still exist and debate about this issue continues. Administratively, there

seems to be an increase in the number of large projects in Japanese fisheries research as one mechanism of tackling these problems and, from the researchers' point of view, as a mechanism to obtain more funding with less restrictions. Agreement on this issue within the research community, however, is incomplete.

An example of funding, from the National Research Institute for Aquaculture, is presented here. Funding generally falls into three categories: (1) small planning studies: funds come from the overall institute budget and usually amount to 200,000-300,000 yen per researcher; (2) special project funding: this involves larger funding from the Fishery Agency, Science and Technology Agency, or MAFF; and (3) environmental-impact studies: these are required studies funded by the Fishery Agency.

4.3 Dissemination and Feedback

Research results are disseminated to fish farmers from prefectural stations primarily through prefectural fisheries extension workers. Fisheries cooperatives play an important role as extension workers are often based there and the cooperative unit provides a forum for training sessions, lectures by visiting scientists, field days, and other exchanges in problem identification and solution. There is one extension worker for every 500 fishermen. Extension involves not only technical advice but also guidance in business management.

4.4 Evolution of the Mariculture Research System

Research data have been accumulating in Japan since the beginning of the Showa Period in 1926. Note that the research system developed after the industry and much research continues to be industry driven. Initially, studies were undertaken on the life history of the main organisms. These studies involved examining feeding habits, reproductive cycles, and environmental requirements (Imai 1971). This information provided a basis for later studies on artificial breeding and culture, which ultimately led to the possibility of completely controlling the life cycle of the major species. Unfortunately, because much of this preliminary information is lacking in developing countries, such possibilities were often overlooked in the rush to develop new aquaculture systems.

Acquisition of this type of information would not have been possible without the development of appropriate research systems and government and private sector supporting structures.

Mariculture, as such, began in the 1600s and various parts of the national infrastructure also developed about this time. In 1774, the Shogunate announced new fisheries regulations. Fish, shellfish, and seaweeds that did not migrate were designated as property of the local village (Matsuda 1979). This was a very

important step in establishing ownership of these resources. Migrating species, on the other hand, such as salmon, could be caught by anyone. During the period 1863-1868, artificial reefs were used successfully in Hokkaido to increase seaweed production. In general, aquaculture was extensive in nature and new technology was either imported from more advanced countries, such as China, e.g., for carp culture techniques, or was developed by trial and error on a local basis.

After the Meiji Restoration in 1868, new development initiatives began as Japan embarked on a modernization drive based on the study and adoption of Western technology. In 1875, the government dispatched the head of the newly established Fisheries School (Suisan Denshusho) to the United States to learn about salmon and trout culture techniques; similarly, other government staff were sent to Germany in 1880 to learn about aquaculture techniques. In 1881, a Fishery Section was established in the Ministry of Agriculture and Commerce. Between 1886 and 1929, a variety of new fishery laws were enacted: the Fishermen's Association Quasi-Law in 1886, the first Fisheries Law in 1901, the Cooperatives Facilities Act for Agriculture and Fisheries Development in 1918, the Salmon and Trout Culture Act in 1919, and the Prefectural Fisheries Experiment Station Act in 1929. These developments resulted in the establishment of salmon hatcheries and sea ranching. In addition, the government produced carp fry for farmers to rear and repurchased undersized juveniles at harvest time. The building of artificial reefs continued as well. Further details on the development of research institutions can be found in Matsuda (1979) and Sato (1987).

4.5 Training and Education System

At present, there is a sophisticated educational system, including specialized fisheries high schools and universities. This is unique in the world in terms of the variety of levels available and their varied development. For instance, at the intermediate level, students can choose to go on to regular high schools or vocational schools in industry, commerce, or fisheries. All of the 40 Japanese fisheries high schools are public schools and offer courses in fisheries and fishery manufacturing, including aquaculture, radio communication, marine engineering, and management. All have fisheries training ships and conduct practical training in fishery related courses, such as fishery operations, food processing, management, aquaculture, radio communications, and oceanography. At the advanced level, there are three basic types of undergraduate colleges in fishery science: those with a fishery science department, those with a fisheries science faculty, and those with a fisheries-related department within a nonagriculture faculty. All of these institutions come under the Ministry of Education, but there is a fisheries university in Shimonoseki operated by the Ministry of Agriculture, Forestry and Fisheries.

At the local level, most municipalities located in coastal areas have fisheries improvement, information dissemination, and guidance centres for the continuing education of fishermen. Also, there are two fishermen's cooperative association schools to provide training on fishing household management and the management of fishermen's cooperative associations.

5. Mariculture Research and Dissemination System

A strong regionally focused research system is one of the key components responsible for the success of Japanese fisheries development. The other important component is an effective dissemination system. Formal dissemination is carried out through prefectural fisheries extension workers.

Public versus private research and dissemination systems often have different objectives. Public research institutions seek to maximize social benefits for their research endeavours, whereas private research firms seek to maximize profits. There is a large public research system in Japan and in Asian developing countries. There is also an expanding private system, particularly in the more "aquaculture advanced" Asian countries, such as Japan. Much of the private research is in the nutrition sector as feed is the single most important input (often amounting to 40% or more of total operating costs) in semi-intensive and intensive aquaculture systems. Two case histories are presented here.

5.1 Introduction of the New "Soft Dry" Pellet Feed for Yellowtail

5.1.1 Problem identification

Until recently, it was believed that yellowtail would not accept a dry pellet feed. The traditional feed for this species (and for red sea bream and related species) was "trash fish" or low value fish, which are caught in large amounts by the fishing industry. Sometimes problems arose due to insufficient quantities of trash fish. More importantly, it was determined that excessive use of trash fish led to self-pollution problems. Because yellowtail culture makes up a major proportion of mariculture production, it has been a major contributor to the self-pollution problem. For instance, in 1988, yellowtail production was about 150,000 t. Farmers used about 38,000 t of formulated feed to make the moist pellets as well as 1.6-1.8 Mt of sardines, which were fed directly to the yellowtail. It appears, however, that many yellowtail fishermen do not see the self-pollution issue as the most serious problem they are facing. This will have implications in terms of their adopting new technology aimed at controlling the problem; they may be reluctant to use the new technology unless the government legislates the use of nonpolluting feeds, as was the case in Lake Kasumigaura (see Watanabe et al. (1989a) for details).

Research on developing a dry diet started in the early 1960s. Initially, trash fish was mixed with a powdered formulated feed (e.g., eight or nine parts trash fish to one or two parts formulated feed), which produced a moist pellet. It had a moisture content of 25-30%, which made it difficult to store. When defrosted, it lost most of its texture and became an amorphous mass, resulting in

considerable waste during feeding in cages (feed conversion ratio (FCR) 6-10:1). Between 1980 and 1984, the Fisheries Agency embarked on a series of projects in Mie, Kagawa, and Ehime prefectures in an attempt to reduce the self-pollution problem. This program resulted in the development of a moist pellet that was made up of 50% trash fish and 50% mash (mainly binder), similar to the Oregon moist pellet sold in North America and used as feed for salmon. This product is usually prepared daily, but can be kept for 2 days if frozen. It had a better texture than the earlier feed, but it was not widely accepted by the industry because the increased cost involved was not offset by better growth rates and production yields compared with that which could be achieved using trash fish. Later, a single moist pellet was developed, composed of formulated feed; it was only necessary to add water. A porous pellet was also adapted from freshwater diets used to feed trout; at present, this pellet is used by some farmers. The porous pellet is dry until water is added; after 10-20 min, it expands and becomes soft and thereby is acceptable to yellowtail. Oil, as a lipid source, is then added to the pellet as part of the process.

Watanabe and co-workers were the first to develop a soft and dry pellet for this species in 1988 (Watanabe et al. 1989a). The new technology was not revolutionary in scientific terms as it took existing technology for extruded pellet manufacture for other species, combined it with the nutrient requirements for yellowtail, and made a pellet that the fish would accept. Acceptability by the fish was the greatest problem to overcome as yellowtail prefer the texture and taste of real fish, being predators in their natural habitat.

5.1.2 Research program

Research was conducted in conjunction with a private feed company, Sakamoto Feeds. Efforts to develop an expanded pellet acceptable to yellowtail began at Tokyo University of Fisheries around 1984. The program involved a series of experiments that varied mixing and cooking times, temperature and pressure, and moisture levels. Then, protein, carbohydrate, and lipid requirements were modified for yellowtail. Much of this research centred on modifying the protein:energy ratio in this new diet. By 1987, tank and later cage feeding trials were being undertaken. Initial results were very encouraging as the fish readily accepted the new pellet and the feeding response was vigorous. Feeding tables and the chemical composition of the feed are given in Table 4. Further details are available in Watanabe et al. (1989a).

5.1.3 On-farm trials

After developing the prototype pellet, a series of trials were initiated with farmers under farmer-management conditions. By mid-1988, this pellet was being field tested by farmers in Sugari, Mie Prefecture (one farmer), and Uwajima,

Table 4. Sakamoto Hamachi (yellowtail) soft dry series specifications.

Type/ Soft dry fingerling pellets 1-3			
Ingredients			
Crude protein	45.0%	Animal matter	68% (fish meal, krill meal)
Crude fat	16.0%		
Crude fiber	3.0%	Cereals	16% (wheat flour, potato starch)
Crude ash	18.0%		
Calcium	2.2%	Other	16% (animal and plant oil, yeast, algae meal, calcium phosphate, powdered liver, wheat germ, wheat gluten)
Phosphorus	1.7%		
Fish weight			
Pellet 1	3.0 mm diameter	10-35 g	
Pellet 2	4.0 mm diameter	20-50 g	
Pellet 3	6.0 mm diameter	40-150 g	
Medication			
Water case: Add 1 kg of feed to 150-200 mL of water, add medicine and mix 2-3 minutes, then feed		Feed oil case: Add 1 kg of feed to 30-50 g (3-5%) feed oil, add medicine, mix 2-3 minutes, then feed	
Specifications			
This high calorie feed makes high growth rates possible. It can be used with medication, thereby keeping fish healthy and providing quick response to diseases such as Pseudotuberculosis.			

Type/ Soft dry pellets 4-9			
Ingredients			
Crude protein	40.0%	Animal matter	65% (fish meal, krill meal)
Crude fat	20.0%		
Crude fiber	3.0%	Cereals	11% (wheat flour, potato starch)
Crude ash	16.05%		
Calcium	2.2%	Other	24% (animal and plant oil, yeast, algae meal, calcium phosphate, powdered liver, wheat germ, wheat gluten)
Phosphorus	1.8%		
Fish weight			
Pellet 4	9.0 mm diameter	100-400 g	
Pellet 5	11.0 mm diameter	300-700 g	
Pellet 6	13.5 mm diameter	600 g-1.3 kg	
Pellet 7	16.0 mm diameter	1.2 kg -	
Pellet 8			
Pellet 9			
Medication			
Use special perforated pellets that reduce uneven mixing and waste			
Specifications			
This revolutionary feed refutes the nortion that yellowtails cannot be raised with dry pellets. This feed produces excellent quality meat, is economical, and results in a high growth rate.			

Source: Sakamoto Feed Co. Ltd. (1990).

Ehime Prefecture (50 farmers), and Kagoshima (10 farmers). Farmer cooperation was based on the following: (1) a willingness, on the part of the farmer, to cooperate under the framework of a subsidized feed input in exchange for following normal farm-management procedures, including keeping accurate records; and (2) any losses in income or production suffered as a result of using the new technology would be covered by the feed company.

A sample of records from the Sugari farm is presented in Table 5. From the feed company's point of view, there were initial concerns that farmers might misrepresent any losses suffered, i.e., attributing losses that were actually a result of poor management practices, red tides, diseases, or nonfeed related problems to the new feed technology. It was also difficult to find suitable farmers in enough different locations to provide a wide variety of test environments, particularly sites with large numbers of cages in one location and using large 20 m x 20 m x 5 m cages. Another setback encountered by the feed company involved scaling-up problems in their production plant as their extruder capacity was not sufficient to meet anticipated demands. From the farmer's point of view, there was an initial reluctance to participate in the field tests of a new unknown product.

As field trials continue, a series of minor changes are being carried out on the technology. For instance, it has been observed that there is more feed loss during winter months than during summer months, presumably due to lower water temperatures leading to lower feeding activity by the fish; normally, the fish feed very actively and all of the feed is consumed shortly after it hits the water surface. During winter trials, however, feed was observed floating outside of the cage, leading to a higher feed conversion ratio (FCR) than during the warmer months. An initial plan involved placing a collar around the cage to catch the feed and prevent it from floating outside the cage and being lost. Another potential approach was to redesign the specific gravity of the feed so that it would not float for such a long time period (a sinking feed). Another problem occurred in August 1989, when many farmers reported major disease problems. It was not clear how much of this was feed related. Efforts to solve these problems are continuing. It is clear from these examples that the technology needs some revision.

Present feeding data indicate that the main advantage of the new soft dry pellet is the improved FCR, presumably due to less feed loss, compared with that obtained using the moist pellet or trash fish.

Other methods of disseminating the technology include showing videos of the technology to extension service staff, farmer cooperative associations, and other interested parties. In addition, the new technology has been featured in newspaper articles, on television, and in scientific papers (Watanabe et al. 1989a) and some semipopular articles.

Table 5. Comparison of present costs versus new technology (assuming no change in labour or capital costs) Sugari, Mie Prefecture.

(A) All moist feed

Month	Moist pellet (kg)	Raw fish (kg)	Moist (kg)	Weight gain (kg)	Cost of medicine (JPY)	Vitamin and nutrition mix supplement (JPY)
8						
9	9720	7740	1980	1899	475500	76000
10	10910	9010	1900	1958	300000	76900
11	9160	7640	1520	1566	329600	59200
12*	7772	6642	1130	764	192000	-
TOTAL	37562	31032	6530	6187	1297100	212100

(B) Soft and dry

Month	Amount of feed given (kg)	Weight gain (kg)	Cost of medicine (JPY)	Weight gain ratio
8	7303	4913	1377310	1.49
9	4640	3083	317000	1.50
10	5200	3286	236200	1.58
11	3090	1281	197800	2.41
12*	1260	273	72000	4.6
TOTAL	21493	12838	2200310	1.67

* One of four cages used.

Plans for future research include further examination of the nitrogen-phosphorus ratio, carcass analysis to examine meat texture, and examination of enzymes in the feed.

5.2 Marine Forum 21

Following imposition of the 200 mile Extended Economic Zone by most nations, Japan felt it was important that productivity be increased within its own 200 mile fishing zone to ensure a stable supply of fisheries products for the nation.

To achieve this goal, "Marino-Forum 21" was formed in 1985 as a research and development organization involving fisheries organizations, private enterprise, and prefectures to contribute to the development of Japanese fisheries through the promotion of joint technical development among government and private industry. Its intent was to develop mariculture in Japan for the 21st century.

The aim of Marino-Forum 21 is to pool the technical development capabilities of the private sector with the efforts of the prefectures with respect to fishery development to develop new technology related to fishing ground development and fish farming within Japan's 200 mile fishing zone.

In 1988, Marino-Forum 21 was made up of 226 member groups. Eight research groups are currently engaged in the following research and development studies and field experiments (Fig. 14).

(1) One group is investigating ways to improve the mooring strength and durability of artificial floating reefs. This involves studies on the structural design of the floating body and the mooring system, and field experiments to evaluate the fish-gathering system and to develop a data transmission system.

(2) A second group is attempting to improve settlement and survival of shellfish larvae by preparing propagation sites for shellfish on the open sea beach. This involves model tank tests to develop a method of controlling the water stream and sand drifting. In addition, studies on developing seaweed beds in sandy beach areas are being carried out.

(3) A third group is looking at culturing bio-feeds. In this regard, a rotifer culture test plant was established in 1987 as rotifers are used as a bio-feed in the mass production of seedlings. Experiments on reducing energy consumption related to seedling production were also carried out. In addition, methods of accelerating the ripening of parent fish by means of enriched diets were studied.

(4) The fourth group tested various artificial microdiets. The results were positive for fish growth and survival, especially in the case of yellowtail, Kuruma prawn, and blue crab.

(5) The fifth group looked at marine ranching (sea farming). Development of a fish acoustic conditioning system was one of the areas investigated. Experiments were also conducted in an attempt to increase productivity in oligotrophic sea areas. These involved the use of fishmeal as a fertilizer for seaweed and the installation of artificial reefs to promote the growth of seaweed. Finally, an offshore station was developed for fish-seed production and intermediate rearing.

(6) The sixth group evaluated the status of current fishing facilities in terms of function, construction, and construction material. Also, studies on available technology to generate artificial upwelling streams to improve plankton growth and promote fish propagation were started.

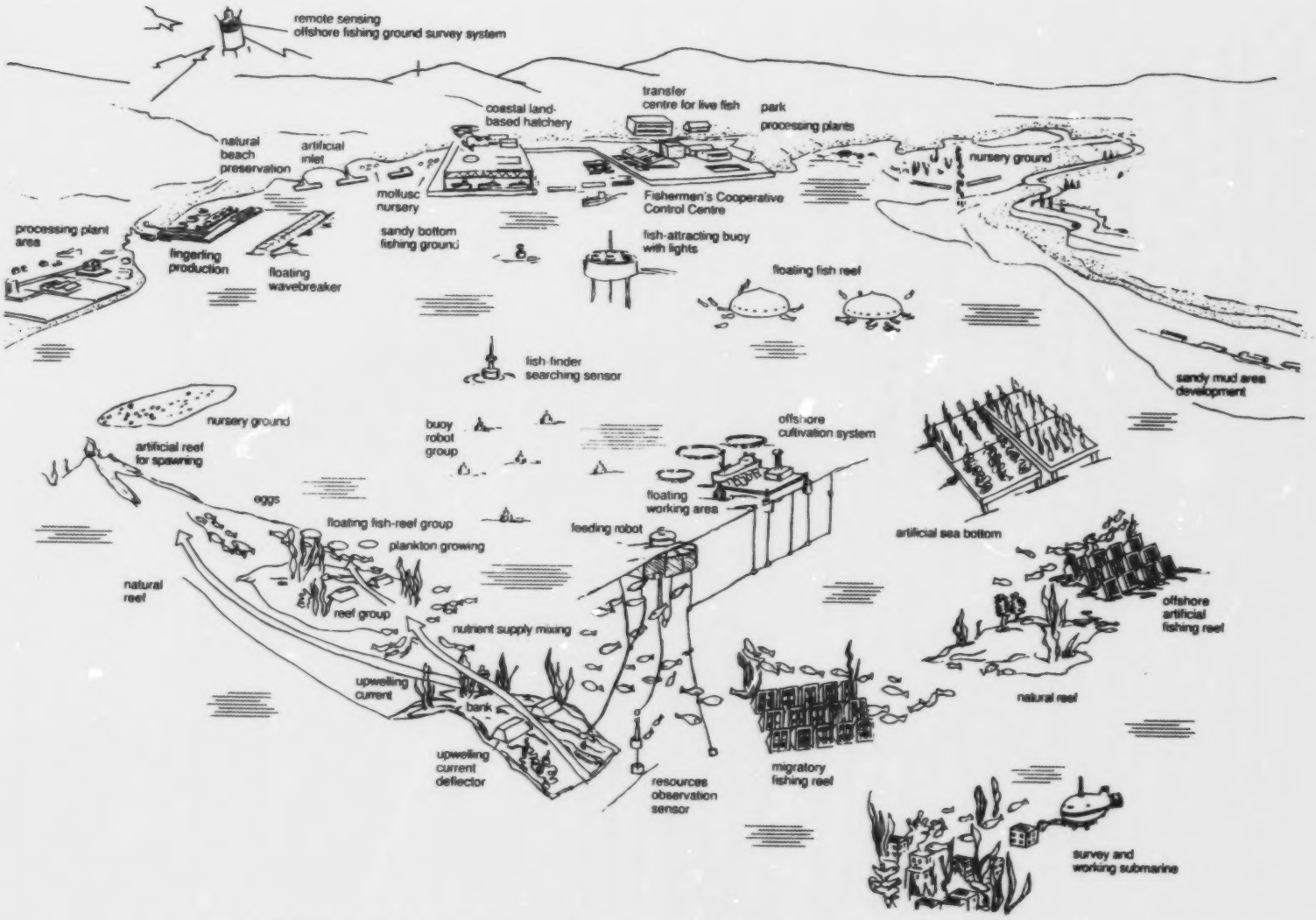

Figure 14. Marine Forum 21 research and development setup.

(7) The seventh group is attempting to develop fish-culture systems for inner bay and offshore use. In sheltered fish culture areas, a submersible fish cage has been used. For offshore areas, two types of cages have been designed: one has a flexible structure, the other is submersible. Both cages were found to be promising.

(8) Finally, Marino-Forum 21 has established 20 working groups that, through a case-study approach, are investigating and examining conditions for comprehensive development and improvement of coastal and offshore areas.

5.2.1 Summary

Marine Forum 21 is a unique experiment in collaboration as well as the development of new technology on a broad technical basis. The close collaboration between users of the technology and researchers in terms of problem identification and solution provides a useful mechanism for dissemination of the technology.

The prospect of comprehensive coastal development is interesting in that it focuses on developing the fishing village with fisheries as the core activity, but fisheries is also coupled with tourism-type activities, e.g., sport fishing, boating, swimming, etc. Fishermen can benefit economically by participating in such businesses if they are carefully integrated into the existing village. This concept combined with new inputs from the biotechnology sector seems to be the main thrust of coastal fisheries improvement.

6. Trends in Mariculture

6.1 Number of Species

One of the obvious trends developing is the increasing number of species being cultured. At present, 27 finfish species (seaweed, shrimp, and mollusc species are not included) are being cultured under traditional commercial conditions (Table 6) (Fukusho, in press). A number of these species still depend on wild-caught fry as the source of seed; however, mass seed production techniques are being developed and scaling-up trials are under way.

The Japan Sea Farming Association has developed a system of seedling production to supplement natural stocks. The results of recent releases of 45 species are shown in Table 7.

Table 6. Marine finfish species cultured under traditional conditions.

Common name	Japanese name	Scientific name
Coho salmon	Ginzake	Oncorhynchus kisutch
Grey mullet	Bora	Mugil cephalus
Japanese striped knifejaw	Ishidai	Oplegnathus fasciatus
Japanese spotted knifejaw	Ishigakidai	O. punctatus
Seabass	Suzuki	Lateolabrax japonicus
Seabass	Hirasuzuki	L. latus
Groupers	Hata	Epinephelus spp.
Nibbler	Mejina	Girella punctata
Red sea bream	Madai	Pagrus major
Porgy	Hedai	Sparus sarba
Crimson sea bream	Chidai	Evynnis japonica
Porgy	Kurodai	Acanthopagrus schlegeli
Porgy	Kitchinu	A. latus
Grunt	Isaki	Parapristipoma trilinea
Yellowtail	Buri	Seriola quinqueradiata
Amberjack	Kanpachi	S. dumerili
Amberjack	Hiramasa	S. lalandi
Horse mackerel	Maaji	Trachurus japonicus
Striped jack	Shimaaji	Pseudocaranx dentex
Bluefin tuna	Kuromaguro	Thunnus thynnus
Rabbit fish	Aigo	Siganus fuscescens
Filefish	Kawahagi	Stephanolepis cirrhifer
Puffer	Torafugu	Fugu rubripes
Rockfish	Kasago	Sebastiscus marmoratus
Rockfish	Mebaru	Sebastes inermis
Rockfish	Kurosoi	S. schlegeli
Flounder	Hirame	Paralichthys olivaceus

Source: Fukusho (in press).

Table 7. JSFA seed production, 1983-1988.

English name	Japanese name	Scientific name	1983	1984	1985	1986	1987	1988
Kuruma prawn	Kuruma ebi	Penaeus japonicus	128000	90000	90000	80670	93500	98100
Blue crab	Gazami	Neptunus trituberculatus	9000	13350	10440	15570	7100	11770
Herring	Nishin	Clupea pallasi	213	416	661	554	645	847
Cod	Madara	Gadus macrocephalus	0	2	4	11	9	4
Tilefish	Akaamadai	Branchiostegus japonicus	-	-	-	0	0	0
Yellow jack	Shimaaji	Pseudocaranx dentex	6	39	133	148	693	821
Yellowtail	Hiramasa	Seriola lalandi	0	1	11	161	56	142
Greater amberjack	Kanpahi	Seriola dumerili	-	-	-	-	-	1
Jack	Buri	Seriola quinqueradiata	953	1210	1253	2618	1191	1934
Almaco jack	Hirenagakanpachi	Seriola rivoliana	-	-	-	-	-	0
Jack	Maaji	Trachurus japonicus	60	257	394	-	-	-
Snapper	Isaki	Parapristipoma tridineatum	412	219	127	179	144	-
Snapper	Kijihata	Epinephelus akaara	8	49	19	83	40	134
Snapper	Madarahata	Epinephelus microson	-	-	-	-	-	0
Seabass	Sujiara	Plectropomus leopardus	-	-	-	-	-	0
Red sea bream	Madari	Chrysophyrys major	4108	4245	1963	4800	4338	4132
Sandfish	Hatahata	Arctoscopus japonicus	-	78	55	150	45	227
Mackerel	Sawara	Scomberomorus niphonius	7	45	30	22	9	20
Scorpion fish	Kurosoi	Sebastu schlegelli	566	717	700	632	530	613
Stonefish	Oniokoze	Inimicus japonicus	4	23	12	24	10	10
Bastard halibut	Hirame	Paaralichthys olivaccus	3805	2567	1701	4439	6695	6224
Righteye flounder	Mushigarei	Eopsetta grigoriewi	-	50	0	4	36	61
Righteye flounder	Akagarei	Hippoglossoides dubius	-	1	2	0	2	12
Righteye flounder	Ishigarei	Kareius dicoloratus	74	8	1	3	11	-
Righteye flounder	Magarei	Limanda herzensteini	22	90	160	244	93	446
Righteye flounder	Kurogashiragarei	Limanda schrenki	65	163	166	192	140	-
Righteye flounder	Babagarei	Microstoma achne	3	26	23	12	39	23
Righteye flounder	Yanagimushigarei	Tanakia kitaharai	-	-	1	3	2	9
Righteye flounder	Matsukawa	Verasper moseri	-	-	-	0	21	51
Puffer	Torafugu	Fugu rubripes	-	-	-	342	168	195
Prawn	Koraiebi	Penaeus orientalis	-	1069	267	234	60	959
Prawn	Toyamaebi	Pandalus hypsinotus	-	10	122	206	785	179
Prawn	Hokkokuakaebi	Pandarus borealis	1	30	29	21	73	2
Prawn	Kurozakaebi	Pandarus	-	0	0	1	5	2
King crab	Tarabagani	Paralithodes camtschaticus	228	172	178	1	177	-
Crab	Hanasakigani	Paralithodes brevipes	416	426	305	166	575	9
Queen crab	Zuwaigani	Chinoecetes opilio	-	0	0	0	0	0
Crab	Kegadi	Erimacrus isenbecki	28	174	298	209	532	544
Crab	Nokogirigazami	Scylla serrata	195	1053	13	219	373	199
Crab	Amimenokogirigazami		-	-	-	-	66	676
?	Kobushime		-	-	-	0	1	1
Cuttlefish	Koika	Sepia esculenta	-	-	-	0	-	-
Cuttlefish	Aoriika	Sepiotenthis lessoniana	2	-	1	0	0	1
Cuttlefish	Yariika		-	5	0	0	0	1
Octopus	Madako	Octopus vulgaris	1	1	0	0	1	5

Notes: Values are x1000. Zero indicates a value of less than 500.

At present, another 80 species are being developed as future culture species (Fukusho, in press). In addition, each JSFA station is trying to develop seed production technology for selected species (Table 8). To date, however, a national system to set interdisciplinary research priorities with respect to these species has not been established. Prefectural, university, and Fishery Agency laboratories are also contributing to this effort.

This new species trend seems to be related to the apparent interest of the consumer in greater diversity and, therefore, appears to be primarily market driven, but it is equally dependent on technology development, initially mass seed production technology.

There is still room for future development of new species as there are many important wild-caught fish species that cannot yet be cultured. In Japan alone, about 500 species of marine fish are landed by commercial fishermen out of an estimated total of about 2800 fish species.

6.2 Marketing

The general marketing system is shown in Figure 15. This system developed from the 1923 Central Wholesale Market Law, which authorized public bodies to establish open markets. There are about 40 Central City Markets and approximately 1000 smaller wholesale markets, some run by public bodies or more often by fisheries cooperatives.

The main marketing trend is that more and more of the species that have been cultured for some time are taking a greater and greater market share relative to wild-caught products. All oyster, pearl oyster, wakame, and nori products are now produced entirely by culture. About 80% of yellowtail and 30% of konbu are cultured. Likewise, more red sea bream is cultured than fished from the wild, despite the higher price commanded by the wild-caught product in most cases. Clearly, the trend is toward greater predominance of cultured fish. However, for some of these species heavy fishing pressure and degradation of habitat have resulted in a decline of fished stocks. At the same time, the ability of the mariculture industry to produce an acceptable product has influenced the shift in the source of production.

6.3 Demand, Supply, Consumption, and Prices

Ministry of Agriculture, Forestry and Fisheries statistics indicate a steady increase (approximately 1-3% per annum) in the demand for fisheries products in recent years; for instance, the total demand for fish was 13.97 million metric tonnes in 1986, an increase of 2.6% from the previous year (Fig. 16).

Table 8. JSFA -- mass production target species.

English name	Japanese name	Scientific name	Station
Herring	Nishin	Clupea pallasi	Akkeshi
Crab	Hanasakigani	Paralithodes brevipes	Akkeshi
Crab	Kegani	Erimacrus isenbecki	Akkeshi
Righteye flounder	Matsukawa	Verasper moseri	Akkeshi
Righteye flounder	Babagarei	Microstoma achne	Akkeshi
Bastard halibut	Hirame	Paralichthy olivaccus	Miyako
Rookfish	Kurosei	Sebastes schlegeli	Miyako
Sailfish sandfish	Hatahata	Arctoscopus japonicus	Notojima
Righteye flounder	Magarei	Limand herzensteini	Notojima
Cod	Madara	Gasus macrocephalus	Notojima
Shrimp	Hokkoku-akaebi	Metapenaeopsis	Notojima
Crab	Zuwaigani	Chionoecetes opilio	Obama (Wakasa Bay)
Righteye flounder	Yanagimushigarei	Tanakia kitahdrai	Obama (Wakasa Bay)
Shrimp	Yamatoebi	-	Obama (Wakasa Bay)
Righteye flounder	Akagarei	Hippoglossus dubius	Obama (Wakasa Bay)
Tilefish	Akaamadai	Branchiostegus japonicus	Miyazu (Wakasa Bay)
Righteye flounder	Mushigarei	Kopsetta grigoriewi	Miyazu (Wakasa Bay)
Cuttlefish	Yariika	-	Miyazu (Wakasa Bay)
Shrimps	Ebi-Rui	-	Miyazu (Wakasa Bay)
Spiny lobster	Iseebi	Panulirus japonicus	Minamiizu
Common sea bass	Suzuki	Lateolabrax japonicus	Minamiizu
Beardfish	Kinmedai	Beryx splendens	Minamiizu
Bluefish	Mutsu	Scombrops boops	Minamiizu
Butterfish	Meaai	Hyperoglyphe japonicus	Minamiizu
Butterfish	Iboaai	Psenopsis anomala	Minammizu
Blue crab	Gazami	Neptunus trituberculatus	Tamano
Snapper	Kijihata	Epinephelus akaara	Tamano
Crab	Nokogirigazami	Scylla serrata	Tamano
Octopus	Madaro	Octopus vulgaris	Tamano
Sharp-toothed eel	Hamo	Murdenesox cinereus	Tamano
Jack	Yashima	Seriola quinaueradinata	Yashima
Globe fish	Torafugu	Fugu rubripes	Yashima
Octopus	Madako	Octopus vulgaris	Yashima
Red grouper	Kue	Epinephelus moara	Yashima
Bastard halibut	Hirame	Paralichthys olivaceus	Setoda
Red sea bream	Madai	Pageus major	Setoda
Sea bass	Kijihara	Epinephelus akaara	Setoda
Sculpin	Oniokoze	Inimicus japonicus	Setoda
Octopus	Madako	Octopus vulgaris	Setoda
Jack	Shimaaji	Pseudocaranx dentex	Furumame
Amberjack	Buri	Seriola quinqueradinata	Furumame
Red grouper	Kue	Epinephelus moara	Furumame
Jack	Shimaaji	Pseudocaranx dentex	Kamiura
Jack	Buri	Seriola quinqueradiata	Kamiura
Red sea bream	Madai	Chrysophyrys major	Kamiura
Sharp-toothed eel	Hamo	Muraenesox cinereux	Kamiura
Prawn	Kurumaebi	Panaeus japonicus	Shibushi
Blue crab	Gazami	Neptunuis trituberculatus	Shibushi
Shrimp	Koraiebi	Penaeus orientalis	Shibushi
Crab	Asahigani	Ranina ranina	Shibushi
Shrimp	Uchiwaebi	Ibaeus ciliatus	Shibushi
Jack	Buri	Seriola quinqueradinata	Goto
Jack	Shimaaji	Pseudocaranx dentex	Goto
Yellowtail	Hiramasa	Seriola lalandi	Goto
Red grouper	Kue	Epinephelus moara	Goto
Cuttlefish	Aori ika	Sepiotenthis lessoniana	Goto
Tunas	Maguro-rui	-	Yaeyama
Jacks	Kanpaachi-rui	-	Yaeyama
Jacks	Hamachi-rui	-	Yaeyama
Groupers	Hata-rui	-	Yaeyama
Crabs	Nokogirigazmi-rui	-	Yaeyama
Cuttlefishes	Koika-rui	-	Yaeyama

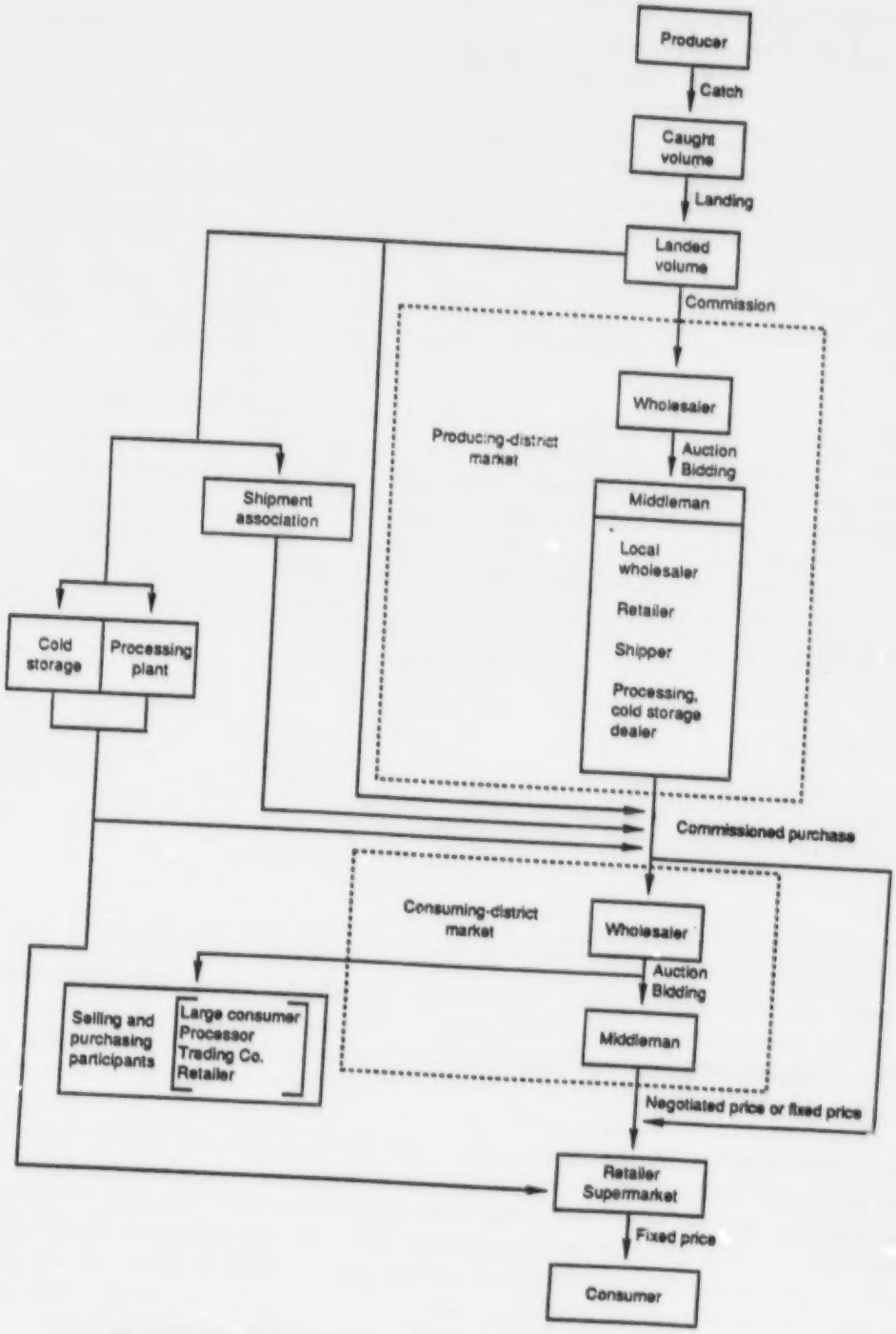

Figure 15. Fisheries marketing system (MAFF 1986).

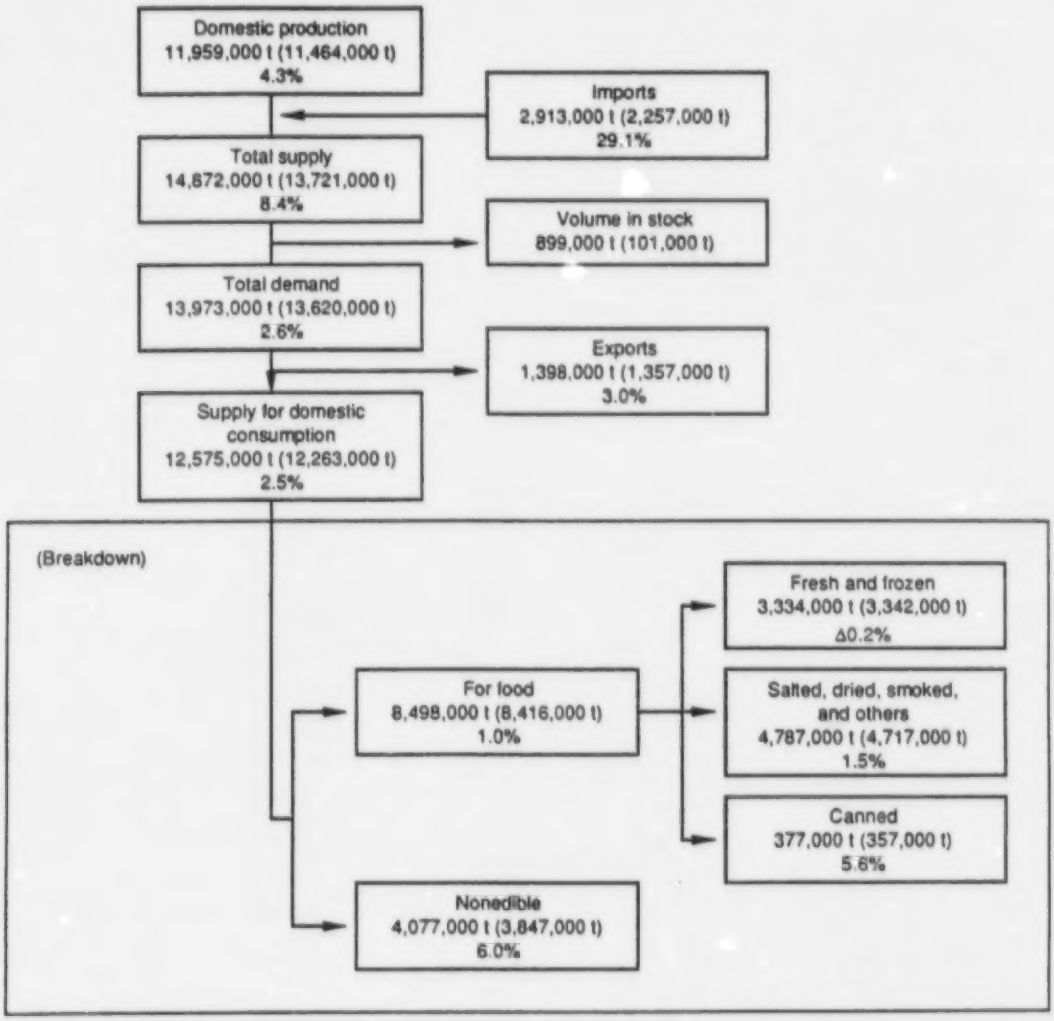

Figure 16. Fish and shellfish -- supply and demand (after MAFF 1988). Note: (1) The numerical values in parentheses are the established values of 1985. (2) The percentages given represent the rate of increase or decrease from the previous year.

Fish supplies, on the other hand, increased by 8.4% in 1986 to 14.87 million metric tonnes, mainly due to increases in domestic production and imports. In previous years, production increased at rates comparable to increases in demand (1-3%). Part of the increase in domestic production was from mariculture. Domestic production of fish for human consumption is being given increasing priority to avoid overdependence on imports. Nevertheless, increasing amounts of fish are being imported, particularly with the present currency exchange rate. In terms of value, fishery production decreased by 6% due to the

decreased value of skipjack, tuna, squid, and cuttlefish. These trends seem likely to continue if exchange rates and current government policies to promote coastal fisheries development, including mariculture, are maintained.

In terms of processed products, there is a trend toward increasing the variety of products produced. Consumers seem to be interested in fish in their diet for its health effects and development of simple handling procedures in line with this need is becoming more common. Also, there is a trend toward extending the types of utilization, with more and more of the previously unused parts being utilized as well as the development of nonfood uses for these items. This seems to be part of an overall trend toward increasing the variety of fish products available to the consumer.

Consumption of fishery products is price related and the net expenditure for fish and shellfish is limited. The proportion spent on fish out of the total food expenditure of a typical Japanese consumer tended to rise gradually from 1965 to a peak in 1978, but now it is continuing to drop. Consumers have cited a feeling of "relatively higher prices" in comparison with the price of other meat. In 1965, for example, fish prices were far below those of meat, but in 1986 they were almost equal to the price of pork and 1.6 times the price of chicken (Table 9). It appears that the total amount of money consumers are willing to pay for fish is limited.

Fish such as jack mackerel, bastard halibut, sea bream, and flounder were purchased in lower quantities when prices increased. Some fish species, such as mackerel, for which the price remained stable, were also purchased in reduced quantities; salted salmon and sardine, however, also with stable prices, were purchased in greater quantities.

Present approximate prices of the main mariculture species reviewed here are shown in Table 10. These prices, although averages, provide a rough indication of the value of various species.

Price is affected by a number of factors: demand, supply, and quality of the product. For instance, a premium price is paid for fresh fish, either just killed, kept fresh on ice (shime), or alive due to its superior taste in the mind of the consumer. The price of many fish also varies seasonally, depending on supplies and location. Figure 17 illustrates this point using wholesale data over 1986, 1987, and 1988 from the Tokyo and Osaka areas. It should be noted that yellowtail prices have declined since 1986. The declining price of yellowtail is one of the reasons many yellowtail farmers are moving to other species.

Table 9. Trends of household consumption by item per capita per annum.

	Total expenditure for food (JPY)	Fishery products						Value of expenditure for meat milk, and eggs (JPY)	Value of expenditure for eating out (JPY)
		Total value (JPY)	Fresh fish and shellfish		Salted and dried fish and shellfish		Others value (JPY)		
			Quantity (g)	Value (JPY)	Quantity (g)	Value (JPY)			
1980	227066	35596	14643	18933	3657	6336	10327	35418	31409
1983	248807	38172	14229	19814	3859	7185	11173	36986	37000
1984	254867	38450	14379	19913	3837	7164	11373	37674	37985
1985	258094	39063	14168	20345	3913	7337	11381	37737	38918
1986	260605	39074	14100	20548	3963	7244	11282	37552	41031
Increase 1984/1983	2.4	0.7	1.1	0.5	▲0.6	▲0.3	1.8	1.9	2.7
or 1985/1984	1.3	1.6	▲1.5	2.2	2.0	2.4	0.1	0.2	2.5
decrease 1986/1985	1.0	0.0	▲0.5	1.0	1.3	▲1.3	▲0.9	▲0.5	5.4

Notes: In the family income and expenditure survey, nonagricultural, nonforestry, and nonfishery households of two or more family members are taken (same in the following). "Others" include fish-paste products, other processed fish and shellfish products, whale meat, seaweed, processed seaweed products, and broiled eels. In "meat, milk, and eggs," whale meat is not included.
Source: MAFF (1988).

Table 10. Wholesale prices of cultured species.

	Alive/fresh	Shime (freshly killed)	Date
Yellowtail	865	-	June 1989
Red sea bream	1725	1406	June 1989
Kuruma prawn	8124 (large)	-	June 1989
	3042 (small)	-	June 1989
Oyster	1259 (without shell)	-	Feb. 1989
Nori	11.44 per sheet (but wide price range of 5.98-15.59)	-	1986

Note: Values in JPY/kg except for nori.
Source: Data from the magazines Yoshoku (Fish Culture) and Zengyoren Norigoyumi (Diary of Seaweed Culture).

Mariculture has a comparative advantage in terms of adjusting to market forces due to the greater control that a fish farmer has in scheduling production to take advantage of these forces. Research on many species is directed toward developing technology to allow total control of the production process. This is not yet possible for all of the species reviewed here and may be impractical in the near future in Japan. Not only must breeding technology be developed to allow out of season mass seed production but technology for rearing live food must also follow suit and hatchery use must be such as to avoid conflict with other desirable species.

Another market opportunity that mariculture might exploit can be illustrated by looking at the present situation with respect to horse mackerel. This fish is caught and mainly used as a feed fish for a number of mariculture species; however, it is also cultured for human consumption.

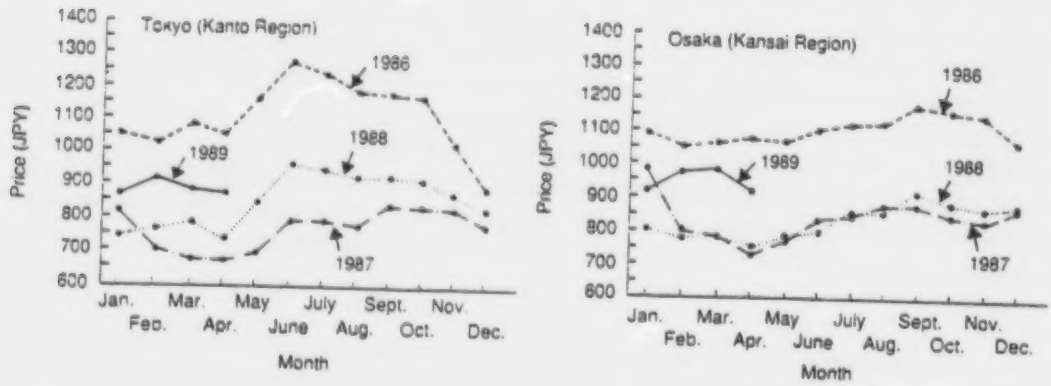

Figure 17. Regional and seasonal wholesale price variation of yellowtail (after Anonymous 1989).

In recent years, increasing amounts of horse mackerel have been used for human consumption. This coupled with decreasing wild stocks has increased the market price for this species. This mariculture value-added approach may be a trend that can be applied to other species, such as sardine.

To further illustrate the increasing examination of marketing strategies in mariculture, T. Watanabe, in Marine Forum Newsletter No. 12 (June 1988), suggested that the Japanese mariculture industry should set artificially high prices and move away from the idea that mariculture products are useful as a general food source; instead, the industry should aim at producing high-quality products, which would have correspondingly higher prices ("luxury items"). Part of the problem with the mariculture industry is that the cost of inputs, such as feed and labour, is increasing rapidly and profit margins are being cut. The self-pollution problem is, in part, an economic problem, as the industry would find it difficult to cover the cost of higher quality, nonpolluting feeds based on present market prices.

Information on the government's pricing policy was unavailable. Although prices of many fish species have been dropping in recent years, it seems clear that MAFF and the Japanese government as a whole place a higher priority on protecting the interests of the producer. This is not totally a one-sided situation as consumers' interests are also protected in the sense that policies are designed to encourage adequate production of quality fish at a reasonable price. However, MAFF still targets much of its efforts on programs designed to raise the quality of life of the Japanese fisherman/fish farmer. The same reasoning pervades other sectors of agriculture (e.g., rice pricing, which is always in the news as being higher than the international price). It is interesting to compare this state of affairs with a statement in the recent TAC (1988) report on sustainability of agriculture: "socio-economic research has demonstrated that increased production has led to falling prices of the main staple foods in much of the world and that the principal beneficiaries have been the poorest consumers.... FAO studies indicate that price policies were significantly less favourable to farmers in Africa than in any other developing regions in the period 1969/71 to 1981/83." By contrast, "For example, the Ugandan government doubled food prices in 1983, resulting in a 400% increase in locally produced food.... It was concluded that the decline in prices was caused by the policies of African governments rather than by declining world market prices." From this point of view, the Japanese policy of maintaining high prices to benefit the producer has some relevance to the LDC situation.

Demand for a given species seems to be limited, at least under specific market conditions; for example, supplies of yellowtail seem to be satisfying the present demand for a cultured product of the present quality.

From a nutrition and human health point of view, the intake of nutrients (e.g., protein, iron, vitamins plus energy) is above required levels except for calcium (MAFF statistics). About 15% of all calcium intake is from fish, but the national intake is still low, on average, particularly when compared with Europeans and Americans, where milk products are the main source of calcium. As mentioned earlier, fish is increasingly being recognized for its health benefits related to low cholesterol levels.

6.4 Culture Systems

There are two general types of mariculture systems: traditional and sea farming. The term traditional covers a wide variety of systems on land (ponds and tanks) or in the sea (cages and pens for finfish; rafts and longlines for oysters and seaweed). Since World War II, there has been a trend toward increasing intensification. At present, most traditional systems are intensive in terms of production per unit volume (e.g., yellowtail cage culture production averages around 15-20 kg/m^3). In finfish culture, most species are cultured in cages rather than ponds or pens as the increased water circulation allows for higher stocking densities.

Since the early to mid-1960s, however, there has been a marked shift away from a primary emphasis on maximum production per unit volume of water. Studies have indicated that problems arise when culture systems are pushed beyond the carrying capacity of an area. The problem is not limited to species that require feeding, but occurs in oyster and seaweeds as well. It is most notable, however, in high feed input systems. Thus, a number of key constraints seem to be impacting simultaneously on the present development of the mariculture industry; three key issues are discussed here.

6.4.1 Labour

With the relatively high cost of labour, there is a trend toward reducing labour costs. For a number of years, there has been a tendency to incorporate labour-saving devices into the fish farming industry as a whole. It is important to note that overall the labour force in the fishing industry has been changing rapidly since the mid-1950s, e.g., the number of fishermen has been decreasing (see Section 6.6, Table 13).

6.4.2 Land

There seems to be a trend away from culture systems on land as indicated by the increasing number of technological developments related to culture systems for the sea. Existing land-based systems are either being phased out or intensified in terms of output per hectare. As indicated earlier, high land prices have made

it uneconomical to build land-based systems, except in the case of some high-priced species.

Intensive tank systems are being developed for culture or seed production of some of the high-priced species that have been cultured since World War II. The high cost of land in this instance is partially offset by the enhanced control of the culture system. This is becoming more and more important due to the major pollution problems occurring in the coastal zone.

6.4.3 Feeding strategies

Feeding (or fertilization for species that feed at lower levels of the food chain) is the main method of intensifying production levels.

Of general note is the fact that all of the early mariculture species fed on plankton or related primary production. It is interesting to speculate why the species initially reared by Japanese mariculturists fed at the lower levels of the food chain. This phenomenon is likely related to the seed production problem, as this was less of a problem for these species. However, I have yet to see an historical examination of this in the literature.

Feeding strategies for species such as seaweeds and oysters (those feeding at lower food chain levels) centre mainly on identifying suitable culture areas. If the intensity of culture is too high, production problems occur. Therefore, there has been a trend toward defining densities that provide optimum culture conditions. However, with the exception of Fuji's (1980) research on scallops in Lake Saroma, there have not been any attempts to accurately define the carrying capacity of coastal areas for specific densities of culture.

Culturing carnivorous species (those feeding at higher food chain levels) is dependent on the supply of low value fish as the protein component in the feed. Table 11 presents the feeding pattern for yellowtail.

Almost 90% of the nitrogen and phosphorus contained in the feed (low value fish are 75-80% protein on a dry weight basis) is excreted, leading to eutrophication of the culture grounds. Since this culture system was first used, farmers have been increasing stocking densities and the amounts of trash fish fed to obtain maximum yields. The suggested stocking density guideline is 6-7 kg/m^3, but farmers often stock up to three times this amount, which leads to self-pollution problems as discussed earlier. The self-pollution problem has a number of facets. It is partially a technological problem as until recently a suitable alternative to using trash fish was not available. It is partially an economic problem and it is not yet clear whether the new soft dry pellet will be acceptable from an economic standpoint. It is also an educational issue as the long-term

Table 11. Feeding patterns for yellowtail.

Year	Amount fed (t)	
	Low value fish	Formulated feed
1966	161392	-
1976	964184	5184
1977	966218	6275
1978	1125438	11311
1979	1315766	8023
1980	1295898	1962
1981	1305609	5719
1982	1302884	5175
1983	1344246	7879
1984	1382161	10204
1985	1256051	24353
1986	1233632	27133
1988	1800000	38000(approx.)

implications of nonsustainable culture systems have to be explained to fish farmers.

Related to the issue of farmer education is the fact that now, particularly during times of disease outbreak, trash fish is often mixed with formulated feed to produce a moist pellet that is fed to the fish. This indicates an increasing awareness on the part of farmers regarding the reasons for this problem. A feed conversion ratio of 10:1 (i.e., 10 kg of trash fish produces 1 kg of high-value fish) is commonly used at present. Since 1980, the use of trash fish in feed has increased very little, whereas the use of formulated feed has increased considerably. There seems to be a trend toward using formulated feeds over the last 5-10 years. Continuation of this trend will require a clearer understanding of the nutritional requirements of all the life stages of all production species. This will require continued effort by nutrition researchers as there are still many gaps in existing knowledge of the nutritional requirements of many species.

At present, formulated feeds are based on fish meal, which is also produced from low value fish, fish scraps, and frames from the processing industry (on average, 6 kg of raw fish are used to produce 1 kg of fish meal). If production of cultured species continues to increase, a variety of problems may lie ahead, particularly related to the availability and price of trash fish. A major question is whether such biologically inefficient practices can be continued in the future.

The trend in feeding Kuruma prawn provides another example of changing feeding strategies. Initially, when the culture system was in an early stage of evolution, clams and mussels were used as feed. As the culture system intensified,

water-quality problems associated with overfeeding occurred. As well, interconnected economic issues became critical as feed usually amounts to about 50% of operating costs. In the Seto Inland Sea, the cost of clam in the shell was USD 0.02/kg in 1963. By 1975, the price had risen to USD 0.09/kg and supplies were insufficient to meet demands. In addition, these feeding practices continued to compound water-quality problems. This combined with the increasing cost of clams has provided a strong stimulus for nutrition research, which focused on establishing the nutritional requirements of this species to allow the development of artificial diets. A commercial grow-out diet is currently available for prawn and its use is increasing. However, acceptance of this new diet is slow as many farmers continue to follow traditional feeding practices.

In summary, increasing production intensity in traditional culture systems through feeding strategies has had a variety of negative impacts. Hence, the ongoing research looking for a variety of new approaches.

The self-pollution problem and other forms of coastal pollution have led to a variety of approaches to deal with this problem, one of which has been the creation of environmental monitoring sections in most government laboratories and the new Red Tide Research Laboratory in the Nansei Regional Laboratory in Hiroshima in the early 1970s.

6.5 Sea Farming

Sea farming has developed as an alternative to traditional intensive culture systems requiring high feed inputs. It started in 1962 in the Seto Naikai (Central Inland Sea), but has been a major focus since 1975 to further develop mariculture in the coastal zone and to augment the incomes of existing fishermen. The principle behind this series of national projects was improved utilization of the large continental shelf off Japan (310,000 km^2), which at the outset produced only 3.4% of mariculture production. The objective was to raise this contribution to 40% by stocking selected species that would occupy many of the underutilized niches combined with a package of other enhancement strategies. It was believed that environmental degradation from pollution and land reclamation combined with the effect of overfishing led to the observed drop in coastal fish production. In the first phase, selected coastal waters were designated as fish farming, artificial recruitment, or transplantation areas. As part of this effort, the government established the Japan Sea Farming Association under the Ministry of Agriculture, Forestry and Fisheries as the national government agency to lead this effort and guide related projects of prefectural stations and prefectural sea farming associations. Applied research and mass seed production were the main objectives in the newly established centres. Fourteen centres have been set up to date, with one in most prefectures throughout Japan (Matsuoka 1989). Some prefectural centres are as large or larger than national centres. An example of

prefectural seed production is shown for the Kagoshima Mariculture Center in Tarumizu City (Table 12). Note the low production for some species in certain years, indicating that seed production technology has not yet been perfected (e.g., Oplegnathus fasciatus and O. punctatus).

In addition, work has included construction of artificial fish habitats for farming, nursery, and/or spawning areas (see summaries in Aquabio, Inc. (1982), Thierry (1988), and Grove and Sonu (1986)), and wave reducing facilities, rocky beach tilling, leveling of seabeds, improvement of sea flow, and extermination of predators. In summary, this program focuses on improving all factors leading to the large natural mortality rates currently being observed in fish populations and in future the integration of all existing technology to develop a controlled system to optimize coastal fisheries production.

An interesting trend in the development of the sea farming concept is the tendency by local governments to gradually turn the operation of these centres over to the local fishermen's association. Initially, all capital costs were borne by the government, but as seed production technology was worked out for each species that the association wanted, the operation of the hatchery and the intermediate nursing and release operations were turned over to the association.

As mentioned earlier, a wide variety of new species are desired by the Japanese consumer. The decision of which new species should be targeted for future seed production and release under the sea farming program is made by representatives of the fishermen's association and staff of the local government fish farming centre. The decision is based on the results of an analysis of desirable species, based on market demand and price; present mass seed production technology or the likely time frame required to establish such new technology; competition from commercial fisheries; and other factors.

Therefore, different prefectures or even city or town hatcheries choose target species based on their own specific interests. This regional and subregional basis for decision-making seems to be a useful approach to follow elsewhere as it results in more appropriate species selection.

6.6 The Japanese Fish Farmer, Fishery Rights, and Cooperatives

A variety of issues are reviewed here from the point of view of the end user or beneficiary of the research -- the fish farmer.

Historically, Japanese fish farmers have been the driving force behind many of the changes that have occurred in the industry and the supporting research and development system. Fisheries, particularly aquaculture, has developed based on a tendency to exert increasing control over the resource.

Table 12. Kagoshima Mariculture Center seed production, 1980-1988.

	1980		1981		1982		1983		1984		1985		1986		1987		1988	
	Total length	No. of seeds	Total length	No. of seeds	Total length	No. of seeds	Total length	No. of seeds	Total length	No. of seeds	Total length	No. of seeds	Total length	No. of seeds	Total length	No. of seeds	Total length	No. of seeds
Pagrus major (Red sea bream)	30	1441	30	1952	30	1592	30	2115	30	1733	30	3021	30	2002	30	3679	30	2177
Oplegnathus fasciatus	30	76	30	96	30	379	30	46	30	409	-	-	30	60	30	147	30	170
Pagu rubripes rubripes	25	310	25	519	27	361	30	593	30	66	30	1094	30	880	30	774	30	1121
Paralichthys olivaceus	30	11	30	99	30	107	30	36	30	162	30	216	30	186	30	226	30	469
Oplegnathus punctatus	-	-	-	-	30	25	30	0.7	30	0.7	0	0	30	25	30	0.4	30	0
Pseudocaranx dentex	-	-	-	-	-	-	-	-	-	-	-	-	50	21	50	45	50	87
Sulculus diversicolor aquatilis	15	34	20	406	20-26	608	20-26	513	20-26	513	20-26	210	20 10	292 90	20 10	346 182	20 10	280 440
Nordotis discus	15	56	20	138	20-25	329	25	260	25	405	25	424	20 10	183 284	20 10	235 144	20 10	75 30
Chlamys (Mimachlamys) nobilis	-	-	10	399	10	610	10	530	10	192	10	191	10	220	10	292	10	166
Babylonia japonica	2	3	3	40	2-7	13	4-10	10	-	-	-	-	-	-	-	-	-	-
Penaeus japonicus	15	11304	15	9462	15	10500	15	13210	15	12520	15	17560	15	17377	15	17619	15	17450
Penaeus semisulcatus	15	130	15	798	15	86	15	60	15	130	-	-	15	440	-	-	-	650
Portunus trituberculatus	-	-	-	-	C1-C5	126	C1-C4	146	C1-C4	424	C1-C4	971	C1-C4	1661	C1-C4	884	C1-C4	1630
Pseudocentrotus depressus	10	100	10	254	10	209	10	300	10	269	10	210	10	143	10	206	10	230

Notes: Total length is given in millimetres. The number of seeds is x1000.
Source: Kagoshima Mariculture Center annual report.

Fundamental to this increase in husbandry is the issue of ownership. Since the inception of oyster and seaweed culture techniques 300 years ago, ownership of these resources was given to the local village. Sea tenure is parallel to land tenure in terms of ownership. This fact is often forgotten in many developing countries where similar transformations are being made from fishing of a common property resource to a husbandry practice of the same resource. To date, trends in the development of fisheries in Japan indicate that only through ownership or a system of fishery rights is there a satisfactory foundation for future development.

As an extension of this ownership, Japanese fishermen developed a system of cooperatives that set in place a mechanism that initially dealt with conflict management in the fisheries. Later, the function of the cooperatives expanded to include business management, taking advantage of economies of scale as well as a means to implement training and related government assistance programs. Mottet (1980), Ruddle (1987), and Ruddle and Akimichi (1984) review the history and system of administration and conflict management that these cooperatives performed in fisheries, including aquaculture. The importance of informal procedures (e.g., small group discussions; verbal communication; peer pressure; consensus building via negotiation within the fisheries cooperative association, including the parties in conflict and the use of go-betweens, were all options used) in addition to formal government mechanisms is emphasized. Formal government mechanisms are used only as a last resort if informal methods prove inadequate, which is rarely the case.

Even before formalization of these legal structures, during Japan's feudal era, there was a well-developed system of local administration of the fisheries and these traditional systems were the basis of the subsequent legal system enacted in the 1901 Fisheries Law. The Fisheries Law of 1949 and the Fisheries Cooperative Association Law of 1948 further refined the administration of coastal fisheries, placing even greater emphasis on control by the working fishermen. Each member of the Fisheries Cooperative Association (FCA) had rights. Demarcated rights were granted for aquaculture and were usually valid for 5 years. These rights applied to small-scale culture of seaweed, shellfish, shrimp, sea bream, and yellowtail. There were two classes of rights: (1) special demarcated rights for aquaculture of different types within a fairly large sheltered but pollution-prone area requiring special management, and (2) demarcated fishery rights for pond aquaculture, particularly where little coordination with other activities was needed.

In most cases, the prefectural government allowed cooperatives to administer the demarcated rights and most cooperatives operated these areas either jointly or divided them among interested members. An example of this system of subdivision is illustrated in Figure 18 for Yusu Cooperative in Ehime Prefecture. In areas where aquaculture is profitable, new people wish to join the

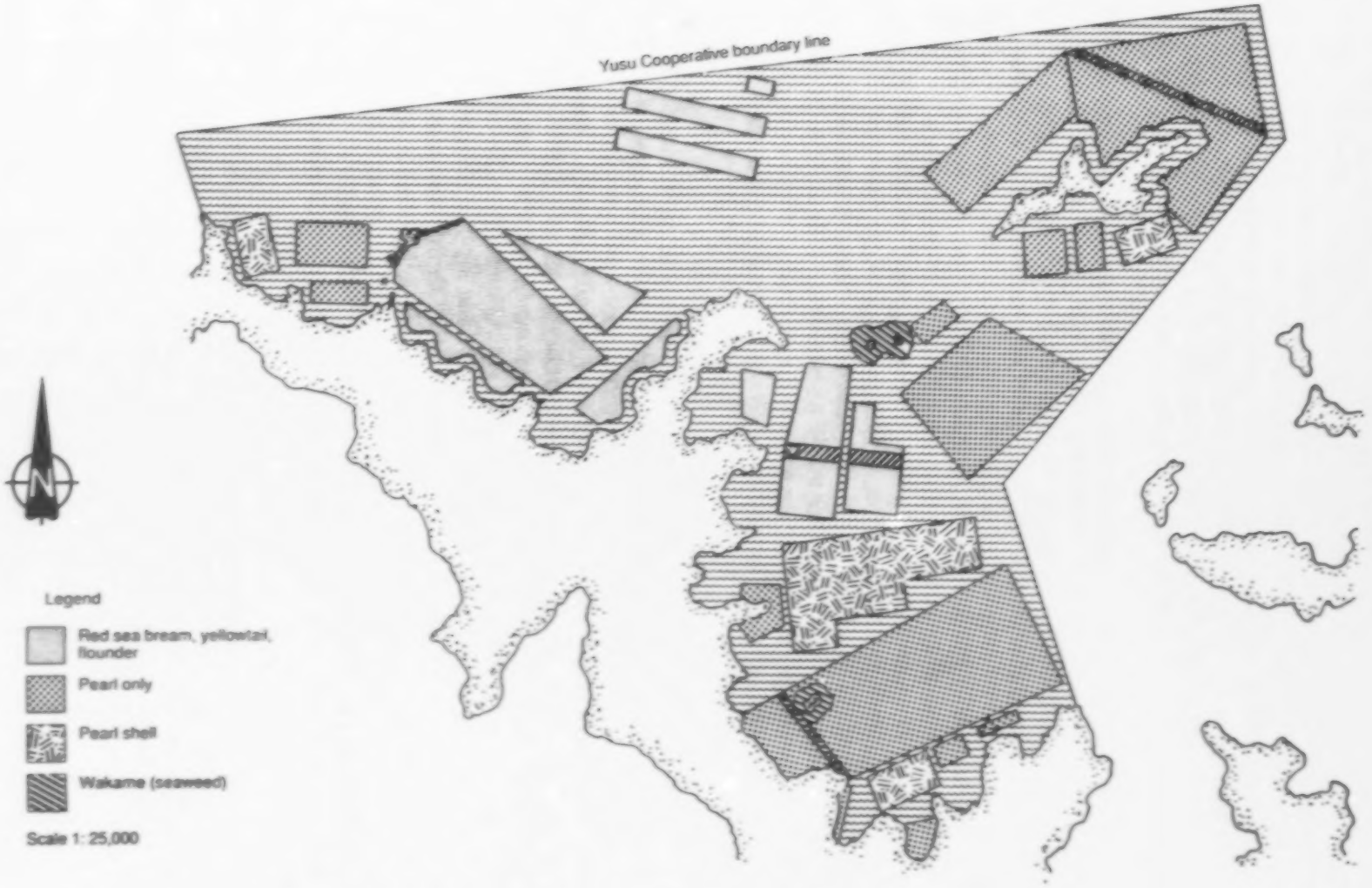

Figure 18. Subdivision of fish culture in the Yusu Cooperative, Ehime Prefecture.

cooperative. In cases where there is adequate culture area available, this is not a problem. In areas where all available sites are being used or where new operations will decrease the profitability of existing sites, however, it may be impossible to gain membership. Even if one becomes a member, this does not guarantee one a culture site. There is also a seniority system requiring that in addition to having lived in the village for 5 years, the applicant must have been a voting member for 3 years and have 3 years of culture experience (Mottet 1980). In some cooperatives, the right to culture a certain species is also allocated. As might be expected, there are a variety of management strategies among cooperatives depending on the market, level of interest, and capital and labour input of individual members as well as the biological capacity of their designated area. Mottet (1980) reviews some of the literature on these approaches related to fundamental issues such as income equalization versus individual inputs.

The FCAs played a crucial role in the success of fisheries and aquaculture development in Japan. Sakiyama (1984) reviews this issue and contrasts the Japanese situation with other Southeast Asian countries. In Japan, FCAs were a strong lobby group in terms of trying to maintain a satisfactory quality of life for fishermen compared with other sectors. As fisheries stocks became overexploited and incapable of maintaining satisfactory incomes for fishermen, aquaculture was one option actively promoted and funded by the government. The FCAs provided a mechanism for educating and training fishermen. Negotiations regarding compensation in cases of pollution of the coastal zone were effectively dealt with by the FCAs in cooperation with the government. Marketing of aquacultural products, credit, and insurance were all services that could be operated through this cooperative system.

Cooperatives also face problems, however. Many small cooperatives are inefficient in terms of offering a wide range of services to members at a reasonable cost. Although there is a national federation of cooperatives to link the many small and different cooperatives, the government is actively encouraging the formation of larger cooperatives. In recent years, there has been a modest decrease in numbers from 3355 in 1985 to 3334 in 1986. By far the greatest number of cooperatives are related to coastal fisheries, including mariculture, with the main functions being credit, input purchases, and training.

In contrast, fisheries cooperatives in most Southeast Asian countries only started in the 1960s and their effectiveness has been variable to poor. This is due to their short history of operation, in part, but a major weakness also results from a lack of education and training on the part of the members. In addition, none of these countries has invested fishing rights in the fisheries cooperatives as was done in Japan since the postfeudal period. It is likely that there were some kinds of traditional rights, but there does not seem to be any documentation of these rights to allow for the development of an administrative structure that incorporates

useful components of such traditional management systems. This is an area where further research is needed that will be important for both fisheries and aquaculture. The cooperative movement in fisheries in Japan clearly shows the benefit of direct involvement of the fishermen in managing the fishery.

In Japan, the structure of the fisheries industry has changed drastically in recent years. Numbers of fishermen have been dropping for some time (Table 13). In addition, the age structure of fishermen has shifted to an older mean age as few younger fishermen are joining the industry (Table 13). Women make up about 17% of the labour force and mainly they are engaged in aquaculture.

In terms of mariculture, there has been an increase in the number of farms for some species; whereas for other species, numbers have been relatively stable or decreased slightly (Table 14).

Mariculture is not a labour-intensive activity as farms have only 2-3 employees. However, most farms are owner operated and often the farmer has a variety of other income sources, including fishing and other types of agriculture.

This raises an interesting issue as many have argued that fishermen, because fishing is a hunting activity, cannot become successful fish farmers as farming is a husbandry practice (see Pollnac (1982) for a discussion of some

Table 13. Number of marine fishery workers, 1983-1987.

	1983	1984	1985	1986	1987
Men	368.3	363.0	356.5	348.8	338.7
15-39 years old	111.5	102.5	97.7	94.1	87.8
40-59 years old	192.5	194.5	188.9	180.7	174.9
60 years old and over	64.3	66.0	69.9	74.0	76.0
Women	78.2	76.6	75.3	73.7	72.4
Total	446.5	439.6	431.8	422.5	411.1

Note: Values are x1000.

Table 14. Changes in the number of mariculture farms (by species).

Year	Yellowtail	Red sea bream	Kuruma prawn	Oyster	Nori
1970	2278	204	77	5407	63162
1975	3292	1192	8	5439	37507
1980	3941	2689	121	6211	28325
1984	3411	2894	142	5781	21297
1985	3201	3014	148	5781	20405
1986	3094	2946	154	5519	18889

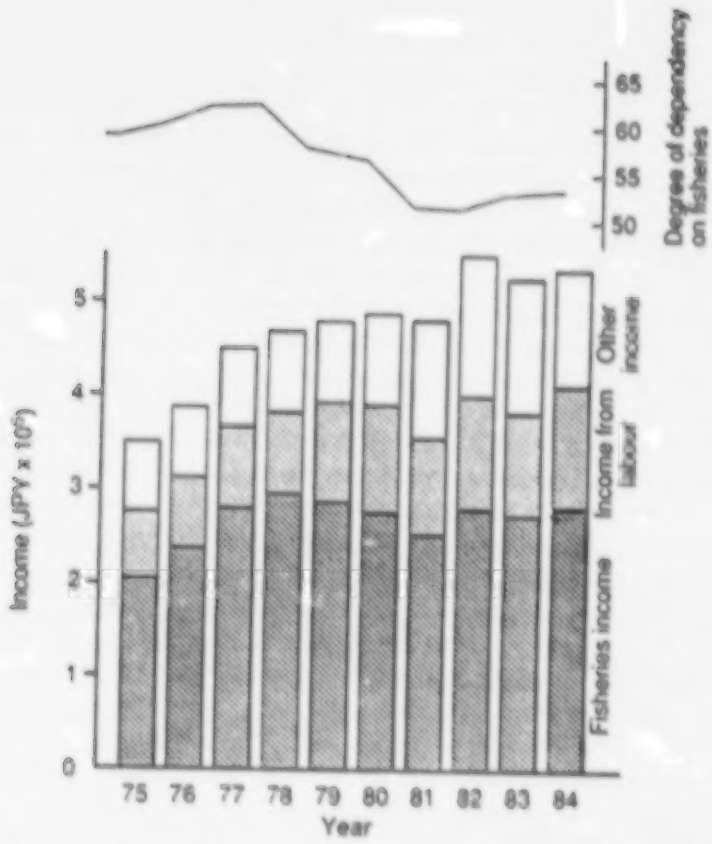

Figure 19. Change in the income of coastal fishermen (after MAFF 1988).

mainly sociological issues). This theory does not seem to be borne out by the Japanese experience, in which case most coastal fishermen are farmer-fishermen. In the coastal villages in Mie Prefecture, fish farmers are also fishermen and grow rice and oranges. Fishermen have adapted relatively easily to a mariculture occupation on either a part-time or a full-time basis. In general, mariculture was accepted in coastal villages when the income from it exceeded that from existing occupations. After mariculture, people working in similar occupations (here fisheries) are most likely to take up aquaculture. There seems to be a limit to substituting one type of aquaculture for another, however, as each species and culture system has a unique history (Matsuda 1979). Also, most cooperatives grow a variety of species, but farms seem to raise only one or two species and, if two, the species are usually related in terms of the culture system (e.g., yellowtail and red sea bream).

Income from mariculture dropped by 3.6% from 1985 to 1986. Income from nonfishing occupations, on the other hand, has been increasing in recent years (Fig. 19). This trend away from fishery options as the main income source is indicative of one of the problems facing the fishing industry with respect to maintaining a satisfactory quality of life in coastal villages (in terms of income, comparable services, etc.). Although aquaculture is an important employment option, it has its limits as well. It is unlikely that it will be able to augment current fishing activities sufficiently to support the present 423,000 fishermen at a comparable quality of life to that of other sectors. Therefore, it seems likely that this trend toward nonfishery employment will continue. There is great concern within the Japanese government regarding how to deal with this issue for the future. Within Japan, there are clear parallels to the situation in other developing Asian countries where the fishery resource is not sufficient to support the existing number of fishermen at a level comparable to other sectors of the population. Nonfishery employment seems to be a necessity in Japan. How to carry out this transformation in an orderly fashion seems to be the main issue.

7. Future Trends in Mariculture in Japan

7.1 Demand, Marketing, and Production

Future demand for fish products is difficult to predict, other than to say that the demand for high-quality fish products by most Japanese consumers will continue. In addition, consumers are becoming more diversified in their purchases of fish. Consumer preference plus price and total supply seem to be the critical factors.

Marketing trends indicate an increase toward eating frozen fish, eating out more often, and purchasing fish products through supermarkets and specialized delivery mechanisms, such as door-to-door delivery. These trends seem to be linked to the diversification phenomenon. Marketing of mariculture products focuses on the specialty niche, where a cultured product may have a comparative advantage. For instance, the Nagasaki Prefecture Institute of Fisheries is undertaking research to produce red sea bream with a higher quality of meat. Diet manipulation, particularly in terms of the protein:energy ratio, is being combined with an exercise program for the fish to develop a flesh with a finer quality. If successful, the product will be marketed as a special "Nagasaki Red Sea Bream." More and more producers are seeking to establish brand name identification for their products and some are seeking marketing arrangements with large food product firms.

In terms of production, the Ministry of Agriculture, Forestry and Fisheries has set a target of a 5% increase in total supplies by 1995 (H. Kanno, personal communication).

7.2 Continued Technology Development and Refinement

A variety of concerns have been expressed by various Japanese scientists regarding future directions of mariculture biotechnical research (Furukawa 1971; Nose 1985; Watanabe 1988a). There are still a large number of research topics for which technology is not yet developed to the necessary level. The future will see an increased need for a multidisciplinary approach to research.

7.2.1 Reproduction

Development of mass seed production techniques was crucial to the progress of the fisheries industry, except in the case of yellowtail and oyster, for which a steady and reliable supply of seed was available from natural sources. Mass seed production techniques have advanced rapidly in recent years. Research investigations on reproduction only started recently, particularly for marine fish, and a great deal of basic information on marine fish, particularly for the main

culture species, is still missing (e.g., maturation cycles and related hormonal patterns under different environmental conditions). Therefore, there will be a time lag while much of this information is gathered and analyzed and before we have a more rational understanding of how to improve this part of the production process.

Spawning is generally of two types: (1) seminatural, where fish are allowed to spawn naturally in a special tank; and (2) induced, where fish are treated with hormones and sperm and eggs are stripped from the fish artificially and mixed together. Although the latter may seem to be the preferred method due to the greater control afforded, natural and seminatural spawning are used by most hatcheries because the fry produced are thought to be more hardy. Also, induced spawning is normally used for more difficult to spawn species or at least until a practical method of natural spawning is established. Theoretically, it should be possible to improve induced spawning techniques to the point that they could completely replace natural or seminatural spawning, but the priority for future research in Japan is likely to be on methods of natural spawning.

For the future, induced spawning technology requires more applied research on the most appropriate hormones, their method of administration, and the time factor involved. At the production level, adaptive research is needed in addition to research at the basic and applied levels. For instance, yellowtail seed, the major mariculture finfish species, is still not produced on a commercial scale, except by JSFA, where induced and seminatural spawning are used to produce seed that are released for sea farming. The large-sized broodstock (8-13 kg) are easily stressed, which may be the main negative factor against induced spawning as handling induces stress. For red sea bream, wild-caught fry are still preferred by many farmers, even though mass seed production has been developed for about 25 years. Market prices provide some indication of this preference: seed from the wild are JPY 350 (10 cm size), whereas hatchery produced seed are JPY 100-150 each (5 cm size) or JPY 200-250 (10 cm size). Much of this adaptive research could be classified under the general heading of improved broodstock development and management, including better methods of selecting future broodstock.

Also, many potential mariculture species cannot yet be mass reared. Research on tuna and related scombroid species (Thunnus sp. and Auxis sp.), for example, started in Japan in 1969, with initial emphasis on developing mass seed production methods. Two types of trials were employed: one involved wild-caught broodstock, which were artificially fertilized, the eggs were stripped, and the newly hatched larvae were then reared in indoor tanks; the other involved rearing juveniles for future broodstock in sea cages after collecting them from the wild. Initial results were unsuccessful, but slowly, year after year, the technology was improved to the point where spawning has now been achieved twice, but not over

the last 5 years. It is expected, however, that mass seed production should be possible in the future. Species with clear production markets but mass seed production problems include striped jack (Pseudocaranx dentex), tiger puffer (Takifugu rubripes), Japanese grouper (Epinephelus akaara), and seabass (Lateolabrax japonicus).

A problem associated with reproduction is larval rearing, particularly the development of efficient methods of feeding. A review of larval rearing can be found in Kuronuma and Fukusho (1984). The development of formulated larval diets for higher priced species is a priority due to the cost and difficulty of rearing large amounts of live food organisms.

Broodstock nutrition is another closely related problem requiring attention. Results will most likely be achieved through combined research on nutrition and reproduction.

Until many of these problems are worked out, it will be difficult for the mariculture industry to take advantage of seasonal price and supply advantages. In addition, further research on related disciplines, such as genetic selection, will not be possible until mass seed production is achieved. Also, further development of sea farming will be limited until such hatchery techniques are established.

7.2.2 Nutrition

There are still major gaps in the development of suitable feeds. Watanabe (1988a), Watanabe et al. (1989b), and Nose (1985) provide specific details on nutrition research; however, a brief summary is given here.

All species depend on the rearing of live foods for the larval stages. Developing these foods took some time as it was necessary to understand feeding behaviour and its development in the larvae (Kuronuma and Fukusho 1984). Again, this indicates the necessity of developing a full understanding of the basic biology of the species before some of the more fundamental problems can be resolved. However, rearing live food is both costly and complicated. Artificial microdiets have been produced, but these are very expensive at present. As technology advances, prices should decrease. There has been little detailed research on developing efficient broodstock diets. This is another area where progress is likely in the future as the nutritional requirements of broodstock are determined. Some species of fish still do not accept artificial dry diets. Until recently, this was the case for yellowtail. Wild-caught yellowtail as food fish still command a higher market price than cultured yellowtail. Fish flesh characteristics such as taste, texture, colour, lustre, smell, and greasiness or fatty flavour are the key factors rated in tests.

Diet plays a major role in determining the quality of fish flesh. Renewed efforts are being made to develop a diet that produces high-quality flesh as well as meets the nutrient requirements of the fish. At the same time, the diet must aid in reducing water pollution and be available at a reasonable cost. A cultured product can likely be produced that is nearly comparable to the natural product. Historically, feed development for "luxury species" has moved from the use of raw fish in all cases to substitution of a partially formulated feed and then to a complete diet, at least for the grow-out stages. Even for the larval stages, complete diets have been developed experimentally and will likely be produced commercially in the future.

The issue for LDCs is what lessons can be learned from the Japanese experience. To date, the same trend as described for Japan is occurring in many LDCs (e.g., in Southeast Asia). In Japan, the move toward greater and greater use of formulated feeds has meant that farmers are mixing less and less of the feeds themselves; instead, they are buying commercial feeds produced at a large central feed mill. In terms of LDC research needs, there is considerable debate regarding whether research should focus on technology designed to allow farmers to prepare simple diets themselves (so-called practical on homemade diets) or should farmers depend on central manufactured feeds. The latter may have advantages of production economies of scale and quality. Homemade diets could be advantageous if the fish protein source, e.g., trash fish, and other ingredients are readily available locally. The main issue centres on economics. Transportation costs will be the crucial issue (mainly transportation of fish meal to the feed mill and subsequent distribution of feed to the farmers versus farmers obtaining these inputs directly.

7.2.3 Disease

Disease research has a high priority within the Japanese research system. Parasites are the centre of attention as they have increased in numbers since TBT was banned as an antifouling treatment. Improved disease control methods will be required in the future and chemotherapy will continue to play a significant role, but research is likely to focus on a series of related problems. Drug usage by farmers is increasing and there is major concern that more information is needed regarding the health implications of drugs on the consumer. Greater emphasis must be placed on alternative procedures for disease prevention, rather than drug treatment. This will necessitate additional education for fish farmers on disease prevention technology.

The development of improved immunological technology is a worldwide trend and the use of modern biotechnology methods to make vaccines is already under way. Protocols to establish what is a healthy or a sick fish are being developed with quick methods for disease diagnosis. As with other disciplines,

disease researchers are frequently involved in joint projects with other research groups (e.g., collaboration with environmental divisions on disease and water quality issues).

Although some diseased-fish problems are being examined in the hatcheries of JSFA, there does not seem to be a routine program monitoring potential pathogen-carrying fish and the implications for natural stocks or other sea-farmed species.

Fish importation laws are also coming under increased examination to prevent the introduction of unwanted diseases.

7.2.4 Genetics

For the future, there seems to be great scope for productive returns to genetic research. At present, however, only limited resources are devoted to this topic. At the National Research Institute for Aquaculture, for instance, there is only a program on population genetics and selective breeding, and this is on the pearl oyster. Research is to start soon on Crassostrea gigas and abalone. There is almost no genetic research (either traditional selective breeding and hybridization or the more modern biotechnology-type molecular studies) on yellowtail, red sea bream, or Kuruma prawn, which are the main mariculture species. Admittedly, some of this research was delayed until mass seed production techniques were established. However, large numbers of fish can now be bred and particularly under the massive program of JSFA there would seem to be a strong need for a more detailed understanding of everything from broodstock selection to genetic contamination of the environment based on an inadequate understanding of the existing genetic makeup of the coastal fish populations and that of the ongoing and planned introductions.

It appears that most future genetic research will be of the biotechnology type as the feeling is that selective breeding and hybridization take at least five generations, which is too long to wait (R. Suzuki, personal communication).

7.2.5 Sustainable mariculture systems

A more holistic approach to the development of new technology is likely to be taken in the future. The self-pollution problem is discussed here in the context of this approach.

The self-pollution problem is a combination of feeding, water quality, and disease problems. Clearly, problems lie ahead. Although Japanese mariculture has made great progress in developing a variety of important technologies, serious constraints lie ahead that will require developing mariculture systems that do not

pollute culture areas. One such problem is related to cage culture systems that go beyond the carrying capacity of the culture area. It appears that for each new species, as culture technology became available from researchers, the technology was applied by the industry at such intense levels that the water became polluted (e.g., sludge buildup on the bottom from uneaten feed and feces, low dissolved oxygen, and higher incidence of red tides); at this time, disease problems developed. This renders the culture area unusable or at least risky for raising a food crop. An additional consequence of this self-pollution problem was increasing usage of antibiotics to reduce the impact of diseases. This led to a variety of associated problems, such as increased drug resistance and concerns over excessive use of medication for a food crop. This, in turn, led to new disease research to establish suitable drug protocols.

The self-pollution problem is not exclusive to Japan, however, as the rapidly expanding prawn culture industry in Taiwan is currently experiencing the same series of problems and they are lamenting that the situation was not addressed earlier (Liao 1989). Liao's article clearly documents the history of the problem and the difficulty in dealing with it once it has been detected. By this time, it is too late. This is an issue that most developing countries should be aware of and researchers should be working to develop necessary policy and legislative guidelines as well as to educate the industry. Most LDC national government institutions have traditionally emphasized the development and promotion of new technology without considering possible negative impacts on the culture environment.

In the international agricultural development community, at present, there is a major interest in sustainability (see TAC (1988) or Lynam and Herdt (1988) for some recent discussions). Lynam and Herdt (1988) define sustainability as "the capacity of a system to maintain output at a level approximately equal to or greater than its historical average, with the approximation determined by its historical level of variability." Clearly, self-pollution as described in this review is, in fact, a sustainability problem. Long-term maintenance of soil fertility in agriculture, for instance, clearly parallels preserving water quality in aquaculture.

In Japan, a variety of options are being examined to deal with this problem, mostly centring on the trade-off of balancing the intensity of culture in a given area versus opening new culture areas.

Reducing the intensity of culture

Research is under way to better define the carrying capacity of different coastal areas under differing culture systems, e.g., Figure 20 shows the relationship of density versus body weight for yellowtail. At present, regulations are set by local prefectural governments on the number of units and type of aquaculture

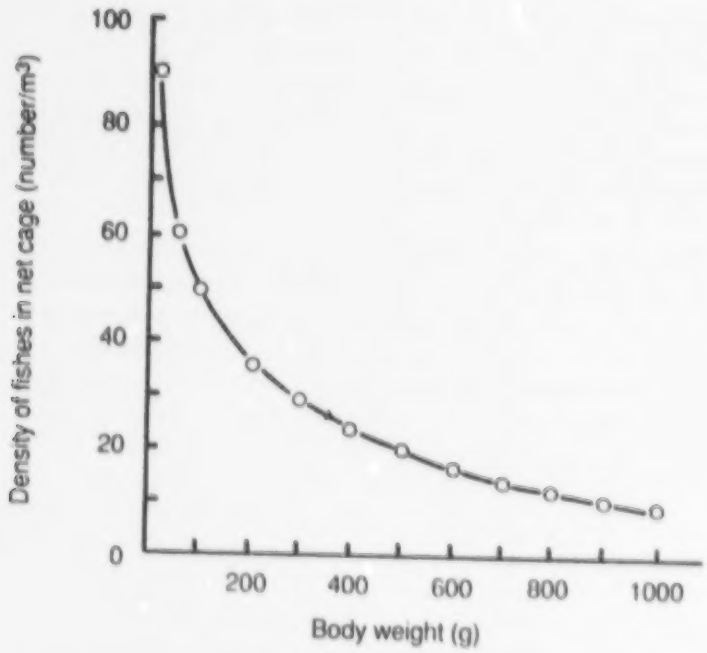

Figure 20. Standard density of yellowtail cultured in a floating net cage versus body weight of the fish.

allowed in specified sites. For instance, the guideline for yellowtail cage culture is 6-7 kg/m³ (Korringa 1976b). However, farmers, in their desire to maximize profits, regularly exceed this limit by 2-3 times. Therefore, there is a need to educate farmers as well as to provide new technology. Even when existing regulations are followed, sludge buildup beneath the cages is still a problem. Therefore, a more detailed examination of the carrying capacity of the coastal zone is needed, including a better understanding of the hydrodynamics and chemistry of marine waters around cage culture sites related to feed and fecal matter buildup.

Shifting culture areas to sites farther offshore

Moving to new areas is another way of dealing with this problem. This would require developing new systems of cage culture (e.g., deep-water cages, associated feeding systems, transport systems, etc.). Some of this technology has been developed (e.g., deep-water submersible cages) or is being developed under the Marine Forum 21 project. Use of submersible cages has not been entirely successful due to difficulties in observing the fish and the higher labour cost involved for feeding and cleaning. In the case of red sea bream, submersible cages were used to darken the red colour of the fish, but a dark cover over the cage proved to be a simpler method.

Under Marine Forum 21, a variety of complex engineering structures are being developed. It is not clear how such structures will be adopted in Japan where the industry is currently focused around small-scale farmers. In fact, large industrial firms are unable to obtain fish culture rights in coastal areas under the current system of regulations, but these regulations may be changed to allow larger firms to test this offshore concept on a practical scale.

In part, the approach of moving to deeper waters is a continuation of an earlier approach of moving to less polluted areas in the nearshore zone. However, most suitable sites in the nearshore coastal zone are already being utilized. Offshore sites will help, but this still doesn't deal directly with the problem of overintensification of culture areas. Also, it will take time to develop the new technology required. Furthermore, the new technology will likely be more costly, more risky, or both.

Land-based tank systems

Land-based systems have been developed (e.g., for flounder and shrimp) that allow for greater control of the culture system. It is doubtful that these systems can be economic in the long term, however, if land prices continue to rise and the price of many of the culture species continues to drop as has been the case to date.

New feeds and feeding systems

Under Marine Forum 21, there is a research component aimed at new feeds and feeding systems. Less-polluting feeds or feeds with low levels of nitrogen and phosphorus are being developed. These feeds must be capable of being transferred about 140 m in water through a pipe from the storage system to the fish cage, which will require a pellet that is water stable for at least 3-4 min. Trash fish and moist pellets are not suitable for this system.

An issue related to these planned developments is that of farmer-made feeds versus manufactured feed. In LDCs, the former is recommended (de Silva 1989) as it is more compatible with the operation of farmer fishermen systems and the availability of inputs, e.g., trash fish, which the fisherman can catch or easily purchase. Others have argued (T. Watanabe, personal communication) that this approach is inefficient and that feed quality will suffer. Theoretically, it is not clear whether a central feed manufacturer would have a greater economy of scale factor as it would be related to the increased cost of transporting trash fish or fish meal to the factory and then transporting feed to the farm versus the availability and cost of the same trash fish to the farmer. An answer to this

question is not yet clear, but the trend in Japan seems to be toward central feed manufacture.

It is still too early to predict the final outcome for all species being cultured in marine waters, but the soft dry pellet for yellowtail is an example of a new technology that can assist in overcoming the self-pollution problem if the feed is widely accepted by the industry. Based on earlier examples, it will take 5-8 years before a final judgment can be made on the acceptability of the new nonpolluting soft and dry feed by farmers.

An example of diet development can be illustrated for carp cage culture in Lake Kasumigaura in Ibaraki Prefecture. Annual carp production was about 10,000 t and with a feed conversion ratio of 1.4:1 about 14,000 t of commercial carp pellet feed (39% crude protein) was being used. This resulted in an estimated 646 t of nitrogen and 118 t of phosphorus being released into the lake water annually from these fish culture operations. These high levels of eutrophication led to self-pollution problems. Further experimentation (Takeuchi et al. 1987; Watanabe et al. 1987a,b) led to the development of new low-protein - high-energy diets (containing only 30-35% crude protein), which reduced the levels of nitrogen being released while retaining the same growth rates at approximately the same cost for the feeds. Related issues, such as the effect of this new feed on the capability of carp to withstand lower winter temperatures in the lake, also had to be evaluated as well as the need for testing new ingredients that would meet necessary protein and energy requirements. All of these details were resolved successfully and in 1983 the government of Ibaraki Prefecture established new regulations requiring that the protein content of commercial diets must be less than 37%.

This example provides a possible scenario for the future application of diets in marine waters. It may be necessary for local governments to legislate protein contents in feeds or some other form of pollution control unless the farmers seek methods to reduce present loading levels in the interest of all concerned.

An ecological approach to mariculture

The present trend is to culture species that feed at higher levels in the food chain. From a theoretical ecological point of view, this is inefficient as approximately 90% of the energy is lost at each step in the food chain (Bardach et al. 1972). Therefore, this type of culture is only practical if economic factors favour such a system (Shang (1981) provides examples and further economic data on this issue). This is the case in Japan at present for most of the new species that are fed trash fish or other high-protein diets. In all cases, these fish have greater market demand and higher market prices, whereas trash fish is

inexpensive. The question for the future is whether this economic situation will continue. This is impossible to predict exactly, but there is increasing concern in the minds of many Japanese researchers and policymakers with respect to the price of feed inputs versus market price.

At present, polyculture systems are not used in Japanese mariculture. Ecologically, polyculture systems are attractive because they offer greater diversity, niche utilization, and more efficient energy cycling. The main disadvantages of polyculture systems, on the other hand, are the larger land area and greater labour input required. Investigations are being undertaken to collect data on polyculture systems.

Sea farming

Sea farming seems to have great potential for the future. Its main appeal lies not in the stocking programs developed so far but in the concept of a total management package to provide optimum production of marine products. Sea farming involves a multiple-species culture concept, using selective artificial stocking to boost local production where needed. Furthermore, it is multidisciplinary in nature, involving the fields of biology, physics, chemistry, social sciences, and information sciences. Whether sea farming will be practical in terms of the fish farmer's goals remains to be seen. Certainly, the ecological approach of relating the management of the organisms to be cultured to their environment is appealing in a conceptual sense.

Sea farming also faces a number of problems in the future related to developing new technology for seed production for an increasing number of species and undertaking efficiency studies (e.g., establishing the best time, size, and place to release species will require considerable research) as well as detailed economic studies on the true costs versus the economic benefits of this hatchery system. In addition, carrying capacity questions must be dealt with on an increasingly wider geographical basis. As species with wider and wider migration areas are being propagated, there is a need to consider not only the capacity in the coastal zone but also the carrying capacity of deeper ocean areas in terms of the associated international complications of fish releases by other countries. Sea farming will become more closely related to fishing as not only releases but also fish capture will have to be estimated more accurately in such studies.

In the coastal zone around Japan, there are increasing examples of conflict between commercial fishermen and sport fishermen, who are catching many of the sea-farmed species. At present, sport fishermen do not require a licence so there is no regulating mechanism for this sector. More research is needed to properly apportion costs and benefits.

As indicated earlier, existing prefectural (or city, town, or other type of local government) seed production centres are increasingly being operated by the fishermen's cooperative association. Initially, intermediate nursing stages associated with rearing fry up to release size were handled by these associations. Lately, as the technology for mass seed production has become established, this work is being turned over to the associations as well. Costs (initially mainly operating costs) must be covered by the associations, which will undoubtedly lead to greater economic efficiency as true benefits are weighed against costs.

A wide variety of species are now being sold according to size or individually. Prices are partially subsidized as the list price does not always cover the total cost or even operating cost. As a general guideline, most finfish seed are sold for JPY 1/mm. Production of some species is still not sufficient to meet demand. Some hatcheries are trying to produce species whose months of production will complement other species, thereby maximizing use of the facilities and staff, which are major costs in hatchery operation. Some hatcheries operate 10-11 months of the year.

7.3 Biotechnology

The Ministry of Agriculture, Forestry and Fisheries states that "biotechnology is the technology for efficiently applying any functions of organisms and is divided into three categories: control of genetic information, control of generation and differentiation, and application of other biological functions" (MAFF 1989).

Only recently has major research been undertaken on biotechnology. Hara (1988) provides some information on biotechnology research and development in the Fisheries Agency.

A Regional Biotechnology Research and Development Program has been set up under which the country is divided into seven blocks, each with a national laboratory as the nucleus. Regionally important topics being investigated include the following: (1) production of supersized salmonid fishes using sterilization techniques, (2) technical development of sex control, (3) production of all-female landlocked masu salmon using sex control, (4) mass production of sterile triploid masu salmon using chromosome manipulation, (5) production of sterile landlocked sockeye salmon using chromosome manipulation, (6) production of superior hybrid seedlings of flounders using genetic engineering, (7) mass production of flounder seedlings using sex control and sterilization, (8) technical development of triploid production of pearl oysters, (9) isolation of nori protoplast and production of hybrids using cloning, and (10) hybridization of sea bream and flounders for aquaculture using gene cloning.

In 1986, the Biotechnology Division of the Fisheries Agency started a project on genetic assessment of major aquatic organisms in aquaculture using isozyme techniques. A project to produce new breeds and biochemicals (hormones, pheromones, antibodies, etc.) by recombinant DNA techniques has also been initiated. Further information is available in the MAFF 1989 brochure Biotechnology Research and Development in Agriculture, Forestry, Fisheries and the Food Industry in Japan.

Much of the present research centres on biotechnology related to reproduction and genetics. Biotechnology is also being applied in disease research to produce a wider variety of vaccines and quick diagnosis kits. It is too early to draw any conclusions regarding the impact of biotechnology studies on mariculture in Japan except to say that the level of interest and present funding are high.

7.4 Fish Imports

One of the major unstated fears of the Japanese aquaculture industry is the threat of foreign competition. Fish imports are increasing, particularly for high-value species, such as prawn, tuna, cuttlefish, octopus, crab, and salmon, some of which are mariculture species. This trend toward increasing imports seems likely to continue, particularly if the present high value of the yen continues. Many developing countries have mariculture industries that are aiming at the Japanese market. In most cases, their costs of production are significantly lower than those in Japan, but product quality is often lower also. This quality will likely improve in the future, however, and it seems inevitable that imports will achieve a greater market share, which may force the Japanese mariculture industry to produce for a more and more specialized "up-market" niche. A trend toward increasing numbers of joint ventures and the transfer of technology to developing countries, especially in Southeast Asia, seems likely to continue for parts of the industry capable of adapting in this way. This may be more difficult for small-scale Japanese fish farmers to achieve.

7.5 New Species

Future research will likely be directed at identifying and testing potential new species for mariculture to meet consumer demand for an increasing variety of species.

Future research priorities related to the number of appropriate new species is a widely debated topic in aquaculture at present. Strong concerns have been expressed by a number of scientists and donor agencies (TAC 1987, 1988) regarding the allocation of scarce research resources to an increasing number of

culture species. Comparisons with agriculture cause further problems as fewer species are currently being researched in agriculture.

International agricultural research under the CGIAR system has a large number of centres, many of which focus their research on a limited number of crop or animal species. In aquaculture, more than 100 mariculture finfish species are at various stages of research and development. If one includes marine seaweeds and molluscs as well as freshwater species (most research and development has historically centred on freshwater species), the case becomes even stronger that aquaculture is based on a much larger number of species than land-based husbandry practices.

Dealing with this issue is one of the main international research priority setting problems to be tackled by research and funding agencies. It is clear that aquaculture research and development must think in terms of multispecies research programs fitted to local situations. At least 30 species seem likely to predominate in traditional Japanese mariculture systems and a high degree of regional specificity, with each bay or area specializing in the culture of a certain group of species, is probable for the future. Sea farming will likely develop similar regional specificities.

The number of species upon which to focus research resources is difficult to predict, but a reasonably broad number seems necessary. Also, research and development systems that maximize the transfer of technology between species should be encouraged to optimize the use of available resources. Present evidence indicates that most Asian national research programs seem to be following the Japanese example, with research projects on at least 10-15 or more species.

It is interesting to note the comments of Harwood (1979) related to small agricultural farm development. He argues that "in intensive farming systems, the critical factor in the efficient use of scarce resources is diversity. As any resource becomes scarce enough to limit production, diversity becomes increasingly important to its optimum utilization." Here, he is referring to diversity in terms of the number of species a farmer is culturing as it allows the farmer to switch or alter the most limited resource (e.g., power, labour, money, nutrients, or water). Such a multispecies concept is likely to become more important in aquaculture in the future as more of the detailed production technology is established for major species.

I would like to suggest the development of a methodology to improve the basis upon which species are chosen. At present, most species are chosen based on general characteristics, such as market price, mass seed technology, feeding (mainly FCR) and growth rate, disease resistance, environment, and suitability. It

would be useful to develop a rating scale for each factor, which could be combined into a new aquaculture species index, for a given region or a set of environmental conditions appropriate for each species.

7.6 Biological Efficiency by Species

If large-volume production of the "best" species of fish is a long-range goal, the level of understanding of the biology of each species should eventually reach the point where comparisons can be made between species in terms of their biological efficiency, i.e., growth under a specific set of environmental conditions. "Best" here indicates most efficient for a given location in a biological and economic sense over an extended time period. For instance, yellowtail is a faster growing species than red sea bream; however, many fish farmers are switching to red sea bream because it is more hardy in terms of its resistance to disease and adverse environmental conditions. Red sea bream takes 3 years to reach market size, whereas yellowtail takes only 1 year.

As more complete biological and socioeconomic data become available, it should be possible to suggest to farmers that under a given set of inputs (fish seed, feed, etc.), a certain output (fish production and profit) is possible. Thus, farmers may be able to choose a combination of species and culture systems to suit their individual situations.

7.7 Improved Aquaculture Planning

Aquaculture, mainly mariculture, has a key role to play in the future. First, however, detailed strategic planning on the future of aquaculture in Japan is needed. For instance, if the top priority new species (e.g., 30 new species) likely to be cultured over the next 10 years can be defined, a more concerted approach can be made on solving related problems. Bearing in mind that the research lag time is 10-20 years, nutrition-related research is a good case in point. When one considers the limited information available on the nutrient requirements of target species plus the need to develop diets for larval, grow-out, and broodstock stages, continued mass seed production may be limited by the lack of suitable diet development for 10 years.

In addition, more interaction is needed among specialists in Japanese aquaculture research. There is a fair degree of interdisciplinary collaboration already, but it is far from adequate to deal with increasingly complex problems, such as the self-pollution issue.

There are a large number of other variables impinging on this issue; nevertheless, some of these issues need careful examination by concerned Japanese authorities.

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